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Coral Reef *In Situ* Product (CRISP): a global compilation of coral reef temperature time series

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Abstract. Coral reef ecosystems are increasingly affected by climate-driven marine heatwaves, but the thermal environments experienced by corals at the reef-scale are still not well resolved by satellite-derived sea surface temperature (SST) products. *In situ* temperature loggers can capture much of this fine-scale variability, including diel temperature ranges, short-term extremes, and depth-dependent structure. However, these datasets are often fragmented across sources, inconsistently formatted, or not readily accessible for synthesis and reuse. To address these gaps, we developed the Coral Reef *In Situ* Product (CRISP), a global aggregation of temperature time series collected from coral reef environments. At the time of writing, CRISP includes 2,548 logger deployments assembled from a mix of public repositories, peer-reviewed literature, gray literature, and community contributions. Each deployment record is associated with available metadata fields stored in a consistent manner across all loggers. The entire dataset is provided in NetCDF format to support use in common scientific workflows (*e.g.*, MATLAB, Python, R). By bringing together these otherwise fragmented observations, CRISP enables analyses of fine-scale thermal variability across coral reef systems. The dataset adheres to the FAIR data principles by emphasizing findability, accessibility, interoperability, and reusability. CRISP can be used for a variety of scientific applications including coral bleaching research, thermal stress assessment, reef climate monitoring, model validation, and investigations of environmental variability across reef systems.

1 Introduction

Coral reefs provide critical ecosystem services, including coastal protection, biodiversity support, and economic value to millions of people globally (Spalding et al., 2017). Yet, coral reefs have become one of the ecosystems most threatened by anthropogenic disturbances. Most notably, climate-driven marine heatwaves trigger widespread coral bleaching (Glynn, 1991; Hughes et al., 2017), the process by which corals expel their symbiotic dinoflagellates (zooxanthellae). This leaves corals susceptible to further damages such as disease (Jokiel, 2004; Miller et al., 2009) and a reduced capacity for carbonate accretion (Jokiel, 2004; Cornwall et al., 2021). Mass coral mortality can occur if a bleaching event is prolonged, leaving reefs vulnerable to degradation and ecosystem loss. In recent years, the increasing frequency and severity of marine heatwaves has driven widespread coral bleaching and mortality across the tropical oceans (DeCarlo et al., 2017; Hughes et al., 2018; Smale et al., 2019; Spady et al, 2016; van Woesik and Kratochwill, 2022).

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Bleaching events are globally monitored by the National Oceanographic and Atmospheric Administration (NOAA) Coral Reef Watch (CRW), tracking prolonged heat exposure on coral reefs to predict the degree of bleaching without direct *in situ* measurements. Instead, CRW employs a satellite-derived sea surface temperature (SST) product with a five-kilometer resolution to assess temperature stress and forecast bleaching using the Degree Heating Weeks (DHW) metric, which incorporates both the magnitude and duration of temperature anomalies above climatological thresholds. DHW has become a widely adopted predictor of bleaching risk, providing measurable thresholds above which varying risks of coral bleaching and mortality can be expected. By enabling near-real-time monitoring without reliance on *in situ* observations, CRW has become a globally utilized tool for large-scale reef management (Liu et al., 2014). However, reefs are not uniform environments; rather, they are mosaics of microclimates shaped by oceanographic, geomorphic, and climatologic factors. Within a single reef, temperature can vary significantly across horizontal and vertical scales as small as tens of meters, as well as over time scales as short as minutes, and is largely driven by water depth, geomorphology, hydrodynamics, and atmospheric forcing (Cyronak et al. 2020; Davis et al., 2011; Leahy et al. 2013; Reid et al., 2020; Rogers et al., 2016; Colin and Johnston 2019; Wyatt et al., 2019). Satellite-based SST products can only provide daily measurements at resolutions greater than 1 km, which are coarser than most coral reef habitat patchiness and therefore lack the spatial and temporal scales necessary to resolve fine-scale thermal variability.

Consequently, satellite-based assessment of reef thermal environments may miss small-scale amplification of offshore anomalies, diurnal temperature variance, temperature structure with depth and internal wave activity that is only detectable with *in situ* loggers. For example, corals separated by as little as 200 m can experience daily temperature ranges (DTR) that differ by up to 5 °C (Davis et al., 2011). Additionally, differences in thermal tolerance between corals of the same species within a given reef have been well-documented (Marhoefer et al. 2021; Palumbi et al. 2014), demonstrating that such variability has important ecological implications as corals exposed to higher DTRs experience improved thermal tolerance and reduced bleaching susceptibility (Brown et al., 2024; Oliver and Palumbi, 2011; Safaie et al., 2018). Furthermore, comparisons of absolute temperatures between satellite-derived SST and *in situ* loggers highlight the limitations of remotely sensed temperature data. Multiple studies have reported strong correlations between satellite and *in situ* temperatures at broad scales but found systematic differences that can exceed 0.5 °C and localized discrepancies of several °C during events such as upwelling (Castillo and Lima, 2010; Claar et al., 2019; DeCarlo et al., 2021, Schramek et al. 2019). While recent studies have introduced new statistical approaches to resolve these differences, thereby improving bleaching forecast skill and reducing regional bias (Whitaker and DeCarlo 2024), coral bleaching models remain limited by the coarse resolution of the underlying satellite SST data. Discrepancies such as these meaningfully affect DHW calculations, underscoring the importance of certain observations that can only be inferred from *in situ* data like DTR and thermal exposure history. As a result, properly calibrated and deployed *in situ* loggers should be considered the “gold standard” for reef temperature monitoring (Colin 2018).

Despite the recognized necessity of *in situ* observations and a wealth of literature utilizing *in situ* measurements, temperature logger datasets can be inaccessible, disjointed, and unpublished. Between site-specific studies and

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monitoring programs, datasets are not standardized or archived in ways that allow for simple reuse. This lack of data sharing and coherent organization represents a significant barrier for advancing our understanding of fine-scale thermal variability and its ecological consequences on coral reefs. To address this gap, we created the Coral Reef *In Situ* Temperature Product (CRISP), a global compilation of (currently) 2,548 *in situ* temperature logger datasets synthesized from multiple online sources across diverse reef ecosystems. CRISP is designed to support large-scale research of reef thermal environments through the aggregation of datasets into a standardized, accessible framework. In doing so, it aligns to the FAIR data principles—findability, accessibility, interoperability, and reusability (Wilkinson et al., 2016), emphasizing the application of scientific collaboration and transparency. CRISP provides a critical resource for refining thermal stress models, improving bleaching forecasting, and broadening our understanding of coral resilience in a warming world.

2 Materials and Methods

2.1 Data sourcing and compilation

The CRISP dataset is composed of global temperature logger data primarily sourced from peer-reviewed publications, digital repositories, gray literature, and direct submissions from researchers. The dataset was designed to capture a broad range of thermal environments and includes data records from coral reef ecosystems across the major tropical ocean basins (Figure 1), although region biases in data density inevitably exist. We developed the CRISP dataset through a systematic pipeline process (Figure 2). In the initial phases, raw temperature logger data and associated metadata were obtained, formatted, and compiled. The subsequent phases consisted of quality control applied to the data and metadata, following the procedures established in Section 2.3. To ensure compatibility across all platforms and long-term accessibility, the compiled CRISP dataset has been made publicly available in the NetCDF format (CRISP.nc).

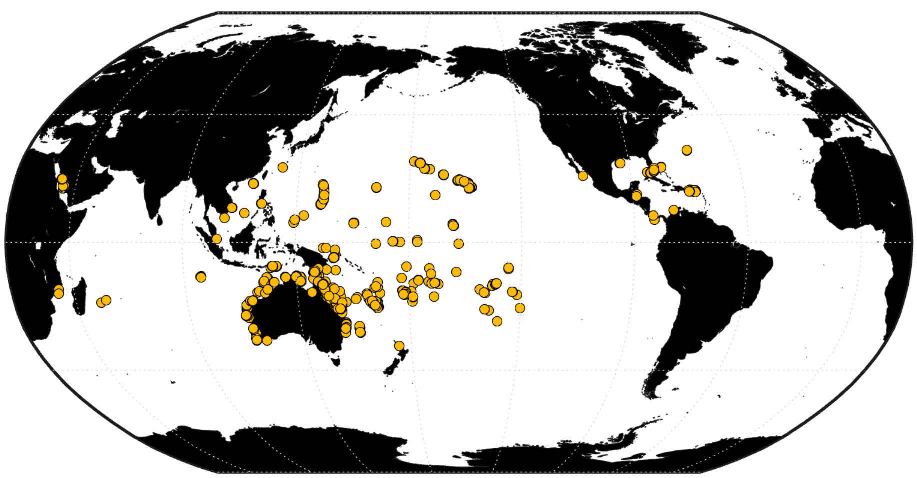

Figure 1. Global distribution of CRISP logger deployments. Each yellow marker represents a unique temperature logger record (n = 2548).

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The CRISP dataset is composed primarily of data gathered from existing online sources, consisting of both government-regulated databases such as NOAA and the Australian Institute of Marine Sciences (AIMS) and university-regulated databases such as the Moorea Coral Reef Long Term Ecological Research (MCR LTER). An additional 314 peer-reviewed papers (based on Rich et al., 2024) that mention the use of temperature loggers were reviewed for data compilation. Temperature records were then extracted from journal articles, supplementary materials, and associated repositories when available. In most cases, raw logger data was not available within the publication, with only 7% of reviewed papers attaching useable temperature logger data in the original publication or through an accessible database. 74% of papers had no attempt at sharing the temperature data records utilized in the study, and another 19% of papers had unavailable or inaccessible data by way of broken weblinks, aggregated (not raw or complete) data, lack of essential metadata, unreadable data, or data only available upon request. Corresponding authors of all publications without useable data (260 authors) were contacted via email with an overview of the CRISP project and a request to share their published data. Only 29% of authors responded, and of those who responded, only 43% shared their data or directed us to a digital repository with the data requested. If two or more emails led to no response, the data were determined inaccessible. In some instances, corresponding authors shared additional unpublished datasets beyond those initially requested. These datasets were often from the same site but not used within their given analysis, providing valuable records that expanded the continuity and spatial density of CRISP.

2.2 Data and metadata standards

Each data record in CRISP corresponds to a single logger deployment and is assigned a unique number identifier (*e.g.*, Logger 1 is identified as "L00001"). This identifier links the raw temperature time series record to its corresponding metadata. Each record consists of temperature measurements from a single logger deployed at a given location, resulting in metadata with single entries of at least latitude, longitude, depth, instrument model, and data source. Some data sources included multiple loggers deployed at the same site but varied essential metadata such as instrument model or depth. In this case, each deployment was stored as a unique record to preserve deployment-specific metadata, resulting in multiple unique metadata entries for a single location. Treating each deployment as a separate record allows for site-specific logger and deployment characteristics to remain attached to the data record they describe.

Each CRISP record includes a minimum set of required metadata fields that are necessary for identifying, locating, and interpreting the temperature observations. Required metadata variables include a unique logger ID, geographical coordinates (latitude and longitude), depth, data contact, data source, date, and time interval. Together, these variables define the most basic environmental and deployment context for each record. Geographical coordinates are recorded as decimal degrees, logger interval is recorded in minutes, and depth is recorded in meters. Some depths were disclosed as a range of possible values due to varying uncertainty (*e.g.*, logger is deployed in tidal zone, or depth was approximated by researcher). Where this was true, the depth was assigned as the midpoint of the range and the provided range reported under the "Notes" column. Data contact is the corresponding author associated with a given data source (*e.g.*, online repository manager, primary author, etc.). The data source field states where each record originated, allowing for reproducibility through traceability. This is typically disclosed as a link to the source data through an article or digital repository but is occasionally not applicable when the source is a direct contributor. In

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this case, the data contact column serves as both the data source and data contact. Time and date metadata were standardized to display year, month, day, hour, minute, and second as one entry to ensure consistency across records regardless of the time format provided by the researcher.

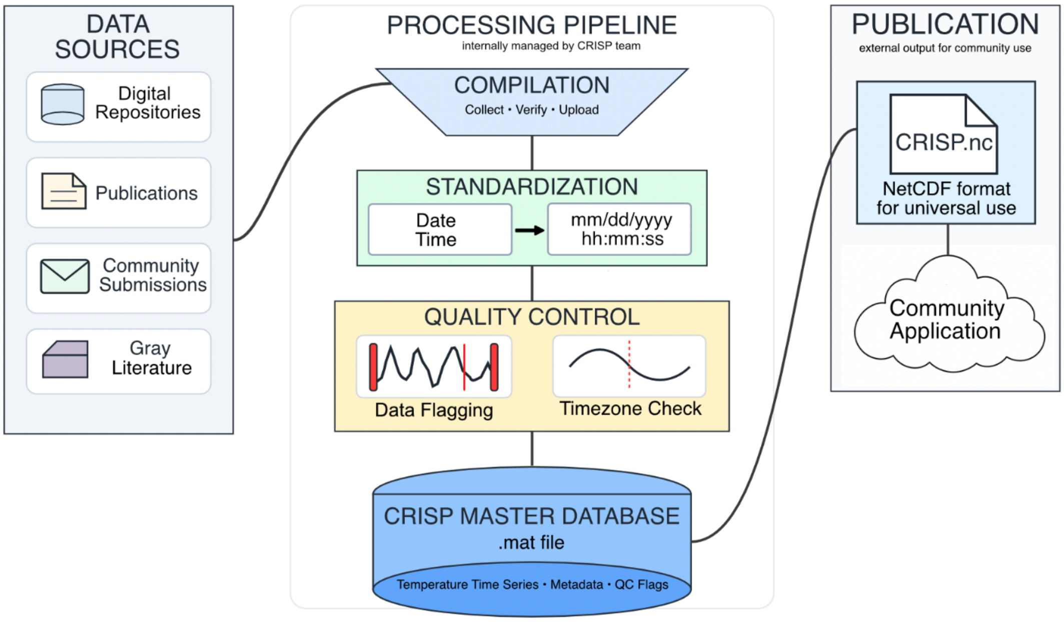

Figure 2. Schematic of CRISP compilation system. We attempted to locate all existing coral reef temperature logger datasets with a multi-pronged approach. We gathered data from the digital repositories of large monitoring programs, datasets linked to peer-reviewed publications, contacting authors of publications referring to relevant data but without immediately accessible data, and searching for relevant data in reports or non-peer-reviewed data depositions. Some unpublished data were also acquired from submissions by individual researchers. Our processing included compiling all the data and associated metadata into consistent formats, verifying time zone accuracy, removing obviously erroneous data, and exporting as a single, easily queried NetCDF file.

In addition to the required fields, CRISP retains optional, non-essential metadata whenever they are provided. These variables include site name, instrument model, serial number, calibration, time zone, and a binary Greenwich Mean Time (GMT, also referred to as UTC) toggle. Although these fields are not always recorded or disclosed by researchers, they improve the traceability and analytical quality of the data record when included. Designated site names allow for quick recall of location by researchers. Instrument type and model provide context as to logger performance as this can greatly vary amongst manufacturers and models. Some instruments are designed for high-precision long-term monitoring, whereas others are lower-cost sensors that may be more susceptible to calibration bias or solar heating under shallow deployment conditions (Bahr et al., 2016; Bainbridge et al., 2011; Lentz et al., 2013; Rich et al., 2024). Recording the instrument model makes it possible to evaluate whether systematic differences in temperature may reflect environmental variation or sensor behavior (Rich et al., 2024). Serial number provides another layer of traceability, especially where multiple units of the same model were deployed in the same region or at the same site. Where information regarding independent temperature calibration is available (*sensu* Lentz et al.,

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2013; DeCarlo et al., 2021), it is included in the dataset; however, in most cases, users should assume manufacturer-stated accuracy. Loggers are assumed to have been recorded in the time zone they were deployed unless reported otherwise. The binary GMT toggle reports values not in GMT (0) and in GMT (1) and is used for the purpose of enabling data analysis to be conducted in the appropriate time zone without modifying the raw time component of each data entry. As data records are not uniform in quality, deployment design, or measurement precision, non-essential metadata fields can provide additional context regarding logger conditions. This information can serve to validate and flag inconsistencies in essential metadata, therefore improving the overall reliability of the temperature record. If one or more of these variables were missing upon data sharing, this information was requested from the corresponding author. If the information was not provided, this did not prevent the inclusion of the data record.

2.3 Quality Control

Quality control procedures were implemented in the data pre-processing stage to ensure consistency across all loggers included in CRISP. These procedures focused on anomalous and erroneous temperature measurements in addition to time zone inaccuracies. For example, loggers may be launched prior to submersion or retrieved prior to the termination of data collection, leading to raw data records with erroneous data where the logger was exposed to air. Additionally, some raw data records included single-standing anomalous temperature values, likely occurring during mid-record logger swaps or low tide in shallow habitats. These data measurements were removed utilizing a cleaning system that allowed team members to identify and flag anomalous and erroneous measurements within a given temperature time series through careful visual observation (Figure 3). No raw data were deleted; rather, a Quality Control (QC) Flag vector of the same length as the temperature record was created to identify and isolate flagged observations. As a result, temperature measurements flagged during the pre-processing stage remain in the published dataset but can easily be masked or excluded from analysis using the QC Flag vector. Time zone quality control was completed by visual assessment of diel temperature cycles. Diurnal temperature heating cycles were plotted in each logger's geographical time zone in addition to GMT time zone for comparison. Occasionally, misalignments between diurnal cycles and time of day were used to infer and correct time zone offsets for loggers in which the time zone of the data as recorded was ambiguous.

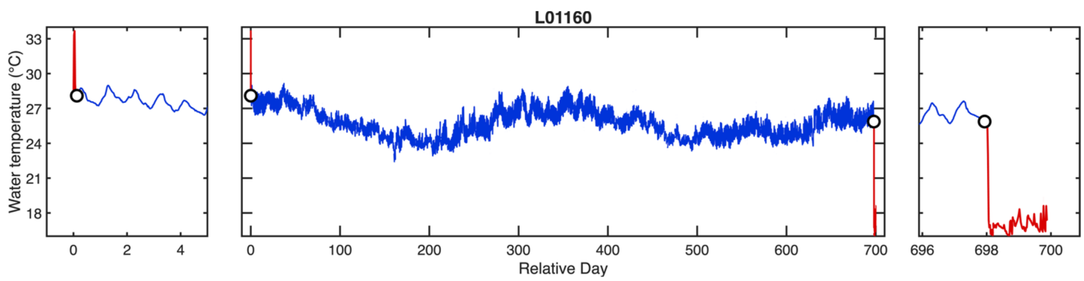

Figure 3. Example of cleaned temperature time series file extracted from the CRISP dataset using the quality control system. Blue data points are considered "good" data and red data points were considered "bad" data. White circles indicate where data were flagged in the time series. L01160 was deployed in O'ahu, Hawai'i, USA.

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3 Data description and usage

CRISP is distributed as an observation-based NetCDF file, providing easier integration across common scientific computing environments and supports future expansion as new records are submitted. It is organized using two primary dimensions: *station* and *obs*. Logger deployments are indexed by the *station* dimension and linked to a unique logger identifier. Station-level variables include latitude, longitude, depth, sampling time interval, logger ID, site name, logger model, serial number, and notes. The *obs* dimension represents individual temperature observations. Temperature observations are stored as time-indexed arrays, while associated metadata variables describe the location, depth, instrument, source, and deployment context of each logger. Observation-level variables include temperature, time, QC Flags, and station_index. The station_index variable links each observation back to the logger deployment from which it originated. The observation-based structure is advantageous as it optimizes storage efficiency and eliminates structural data gaps that occur due to differing logger lengths. Unlike a typical matrix format, which requires placeholder values to accommodate loggers with varying start dates, end dates, and sampling intervals, this structure will only store active temperature observations (Figure 4) while maintaining links to the associated deployment metadata (Table 1). This observation-based system enables users to subset the archive by geographic region, depth range, temporal window, instrument type, or data source without needing to handle individual raw files.

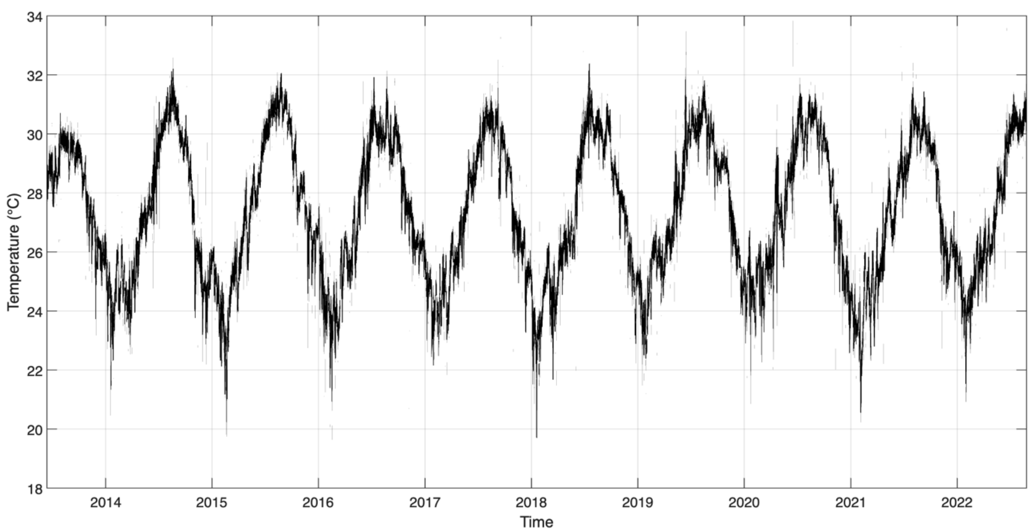

Figure 4. Example temperature time series extracted from the CRISP dataset. Logger L00404 was deployed at Crocker Reef, Florida Keys, United States of America over a span of 9.2 years and experienced temperatures ranging from 19.7°C to 32.4°C.

Table 1. Example metadata and summary statistics extracted from the CRISP archive. Logger L00404 was deployed at Crocker Reef, Florida Keys, United States of America. Metadata fields stored within CRISP include geographic coordinates, depth, sampling interval, and instrument model. Additional summary statistics were extracted to further characterize the deployment.

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Field	Value
Logger ID	L00404
Station index	249
Site name	Crocker Reef
Logger model	HOBO Water Temp Pro V2 (U22-001)
Serial number	Not available
Latitude	24.9091
Longitude	-80.5257
Depth (m)	3.96
Sampling interval (min)	15
Record start	13–Jun–2013 12:00:00
Record end	26–Aug–2022 15:15:00
Record length (days)	3361.1
Record length (years)	9.2
Number of observations	322,670
Mean temperature °C	27.4
Minimum temperature °C	19.7
Maximum temperature °C	32.4
Temperature range °C	12.7

At the time of writing, CRISP contains 2,548 unique logger records and more than 595 million individual temperature observations spanning 69 years of data collection from 1958-2026. When combined, the logger records exhibit substantial variability in sampling density and interval, with an average of 233,675 observations per logger and median sampling interval of 10 minutes. Deployment durations average 1,512 days with the longest record extending 17,147 days, equivalent to 4.1 years and 47 years, respectively (Table 2).

Table 2. Summary statistics of the CRISP NetCDF archive as it stands at the time of writing.

Metric	Value
Number of logger records	2,548
Total valid temperature observations	595,403,751
Mean observations per logger	233,675
Maximum observations in one logger	1,850,247
Median sampling interval (minutes)	10
Minimum sampling interval (minutes)	0.1
Maximum sampling interval (minutes)	1,440
Mean deployment duration (days)	1,512

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Maximum deployment duration (days)	17,147
Number of active years represented	69
Maximum active loggers in one year	934
Earliest record start	19–Jul–1958 07:00:00
Latest record end	04–Mar–2026 13:00:00

Depth is a critical metadata field when interpreting *in situ* reef temperature as thermal variability can differ substantially across reef habitats. CRISP contains a broad range of depths, with an average deployment depth 10 m. Most logger records originate from shallow reef environments, with 95% of deployments occurring within the upper 25 m of the water column and the highest concentration of deployments occurring within the upper 10-15 m. The frequency of deployments substantially decreases below approximately 30 m, though a small number of records extend to nearly 90 m (Figure 5a).

Most logger records span between approximately 1 and 5 years, with the average record length at approximately 4.1 years. The distribution is right-skewed, indicating that while the majority of records are relatively short in duration, a smaller number of records extend over much longer periods. Record lengths exceeding 10 years are uncommon but remain well represented within the archive, and several deployments span more than 20 years (Figure 5b). This provides CRISP a rich historical record and allows long-term temporal analysis of temperature measurements on reefs.

The number of active logger deployments increased steadily from the late 1980s through the early 2000s, followed by rapid growth beginning around 2010. Active coverage reached a maximum of 934 logger records in 2015, reflecting a period of expanded coral reef monitoring efforts and additional active studies on coral reefs. Following this peak, the number of records gradually declined toward the most recent years represented in the archive (Figure 5c). This decrease is likely the result of unpublished recent-year datasets and ongoing data acquisition rather than a decrease in monitoring. Collectively, the diverse structural and demographic characteristics make CRISP a highly robust asset.

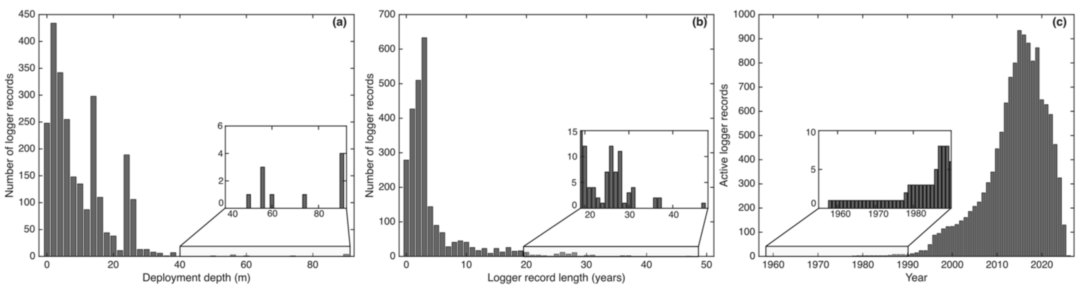

Figure 5. Characteristics of the CRISP archive. (a) Distribution of logger deployment depths. (b) Distribution of logger record lengths. (c) Number of active logger records represented in a given year.

4 Limitations

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Certain limitations associated with temperature logger data are largely contingent on metadata reliability and researcher disclosure. Not all temperature logger instrument models are created equal and are associated with varying degrees of error between and within manufacturers. Specifically, certain Onset Hobo Pendant models are known to exhibit substantial solar bias when loggers are deployed in shallow environments (<5 m). Unshaded loggers can display extreme bias of up to 2-3 °C (Rich et al., 2024), potentially leading to overestimation of thermal stress, bleaching thresholds, and inferred coral resilience. While shading loggers can mitigate some of the solar bias, most loggers in the CRISP dataset are not reported to have been shaded. Therefore, it must be assumed that loggers are not shaded unless explicitly stated. Shading status is disclosed under the Notes column when applicable. Some records lack specification of the instrument model entirely, limiting the ability to assess model error.

Further limitations regard systematic uncertainties in metadata. For instance, a handful of logger files from AIMS do not disclose a precise depth and instead, are reported to have been placed below the lowest historical astronomical tide. While this suggests logger deployment is relatively shallow, precise depth cannot be inferred and ultimately constrains data interpretation. Similarly, tidal changes in sea level result in variable depths over the course of logger deployment. Loggers may be deployed at a certain depth, but this will be variable dependent on tide cycle and range, unless the deployment depth is pegged to a tide level (*e.g.*, reported as depth relative to mean sea level). Ultimately, this can greatly change the temperatures that a coral will experience.

Additionally, spatial inaccuracies may be present as reported logger coordinates can reflect an approximate site location rather than a precise one. Discrepancies such as these can influence fine-scale variance in depth and habitat. All known limitations are documented under the Notes column of each logger. Records lacking complete depth, instrument, or deployment-context metadata may still be valuable for regional temperature characterization but should be used cautiously in analyses requiring fine-scale vertical structure or sensor-specific accuracy.

5 Additional notes

5.1 Code and data availability

The current version of the CRISP dataset is available at https://doi.org/10.5281/zenodo.21045962 in NetCDF format (Larson et al., 2026).

5.2 Citation

The CRISP data product is to be cited when the dataset is used in any capacity (in whole or in part). Whenever possible, the original publication and/or data source should be cited as well. We also encourage users to include the corresponding author(s) of the primary data source in their acknowledgements.

6 Conclusion

The CRISP dataset was developed with the intention of building a centralized and accessible archive for *in situ* temperature logger data on coral reef ecosystems. Despite the wide collection and utilization of *in situ* temperature

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data, these data records tend to be scattered across publications, monitoring programs, and archived data files, leaving them inaccessible for use. As a result, their broader value may not be fully realized, limiting the scope of long-term or large-scale analyses. In many cases, data records end up being used once and then are effectively lost to the wider community if not shared effectively. The CRISP dataset brings these records together in a single, standardized repository to make better use of existing data and allows for improved comprehensive synthesis work.

The development of CRISP reflects an intentional emphasis on accessibility, transparency, and data interpretation. The repository is structured to align with FAIR data principles (Wilkinson et al., 2016), ensuring that datasets are findable, accessible, interoperable, and reusable. Datasets are findable through standardized metadata and consistent file structure; data are accessible through a centralized and openly distributed NetCDF repository; files are formatted to ensure interoperability across common scientific computing environments; and records are reusable due to the inclusion of required metadata fields, quality control procedures, and standardized formatting that support cross-site comparisons and large-scale synthesis analyses. All these factors work to reduce ambiguity and improve compatibility across the CRISP dataset as the records were collected under varying methodologies. This is especially important for comparisons across sites or regions, where differences in deployment specifics like logger type, deployment depth, or sampling interval can otherwise complicate interpretation. *In situ* temperature records capture fine-scale variability that is often missed by satellite products, which makes them particularly valuable for understanding the conditions that corals experience beyond coarse satellite measurements. This includes factors like short-term temperature fluctuations, localized thermal stress, and the influence of reef geomorphology or hydrodynamics. By compiling all these records into one consistent format, CRISP enables exploration of such environmental conditions that vary across habitat and reef type.

Author contributions

AGL, TMD, AS, OJ, EJ, and AGH are the members of the initial CRISP team, and all contributed to the data compilation process. AGL, TMD, AS, and OJ managed the database and constructed organizational structures. AGL and EH completed quality control checks. TMD and PLC contributed datasets to CRISP. AGL wrote the initial manuscript. AGL, TMD, AS, OJ, EJ, AGH, and PLC edited the manuscript.

Competing interests

The authors declare no competing interests were present.

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Datasets in CRISP from NOAA may be accessed from https://www.ncei.noaa.gov. Datasets in CRISP from AIMS may be accessed from https://www.aims.gov.au/data. Datasets in CRISP from ReefTEMPS may be accessed from https://www.reeftemps.science/en/data/. Datasets in CRISP from NOAA may be accessed from https://mcr.lternet.edu/data.

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