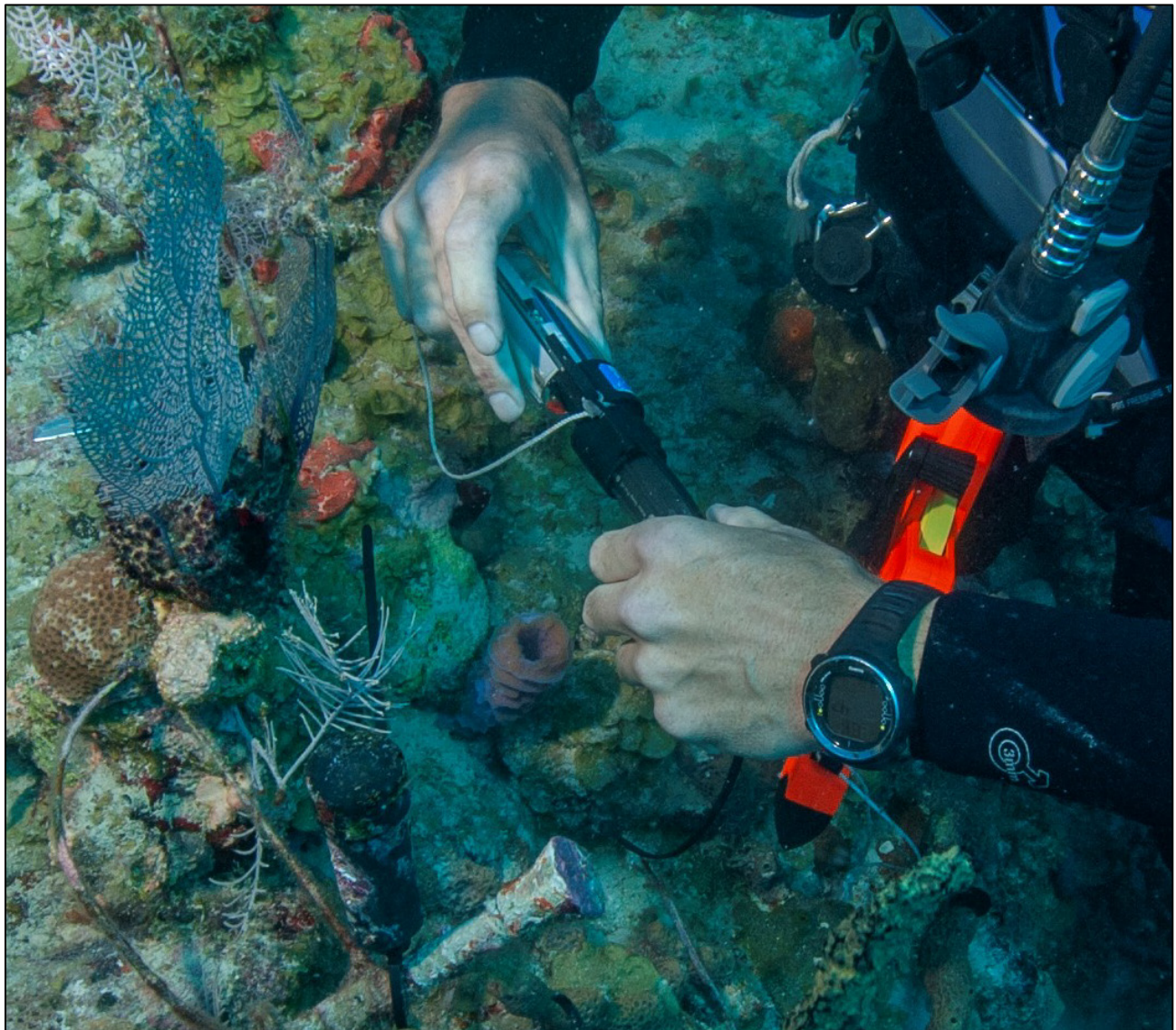




Coral Reef Ecosystem Water Temperature Monitoring

Protocol Narrative—Version 1.1

Natural Resource Report NPS/SFCN/NRR—2021/2262



ON THE COVER

A temperature logger is downloaded to a HOBO® U-DTW-1 Underwater Shuttle.

Photo by Rob Waara

Coral Reef Ecosystem Water Temperature Monitoring

Protocol Narrative—Version 1.1

Natural Resource Report NPS/SFCN/NRR—2021/2262

Andy D. Davis,¹ Andrea J. Atkinson,² Michael W. Feeley,¹ Jeff Miller,² Judd M. Patterson,¹ Lee Richter,² Caroline S. Rogers,³ Robert J. Waara,¹ Kevin R. T. Whelan,¹ Mario Londoño¹

Collaborative project of

National Park Service Inventory and Monitoring Program, South Florida/Caribbean Network,
Virgin Islands National Park, National Park Service
U.S. Geological Survey—Florida Integrated Science Center

¹National Park Service
South Florida/Caribbean Network
18001 Old Cutler Rd., Suite 419
Palmetto Bay, Florida 33157

²National Park Service
South Florida/Caribbean Network
1300 Cruz Bay Creek
St. John, Virgin Islands 00830

³U.S Geological Survey
Southeast Ecological Science Center
Virgin Islands National Park
1300 Cruz Bay Creek
St. John, Virgin Islands 00830

June 2021

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data, and whose background and expertise put them on par technically and scientifically with the authors of the information.

Views, statements, findings, conclusions, recommendations, and data in this report do not necessarily reflect views and policies of the National Park Service, U.S. Department of the Interior. Mention of trade names or commercial products does not constitute endorsement or recommendation for use by the U.S. Government.

This report is available in digital format from the [South Florida Caribbean Network website](#) and the [Natural Resource Publications Management website](#). If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Davis, A. D., A. J. Atkinson, M. W. Feeley, J. Miller, J. M. Patterson, L. Richter, C. S. Rogers, R. J. Waara, K. R. T. Whelan and M. Londoño. 2021. Coral reef ecosystem water temperature monitoring: Protocol narrative—version 1.1. Natural Resource Report NPS/SFCN/NRR—2021/2262. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/nrr-2286599>.

Change History

Protocol revision and version information.

Revision Date	Author	Changes Made	Reason for Change	New Version #
4/27/2020	Lee Richter	1. Reduced number of temperature monitoring sites in DRTO. Added one temperature monitoring site in BUIS. 2. Increased replacement schedule from 4 to 5 years 3. Data management procedures changed to reflect database shift from MS Access to Aquarius 4. Added rationale for monitoring Windspirit site	1. Water temperature was oversampled in DRTO. Added mesophotic BAR coral monitoring site in BUIS (water temperature is co-located) 2. Based on manufacturer's recommendations 3. Database changed from MS Access to Aquarius 4. Improve documentation of monitoring site selection	1.1

Contents

	Page
Change History	iii
Figures.....	ix
Tables.....	xi
Standard Operating Procedures (SOPs)	xiii
Executive Summary	xv
List of Acronyms	xvii
Background and Objectives	1
Rationale and Background	1
Measurable Objectives	4
Sampling Design.....	5
Rationale for Selecting this Sampling Design over Others	5
Applicability to Coral Reef Monitoring	5
Efficiency and Cost Effectiveness.....	5
Very Low Environmental Impact.....	5
Site Selection and History	5
Number and Location of Sampling Sites.....	6
Virgin Islands National Park (VIIS):.....	11
Buck Island Reef National Monument (BUIS)	13
Salt River Bay National Historic Park and Ecological Preserve (SARI)	13
Biscayne National Park (BISC).....	15
Dry Tortugas National Park (DRTO)	17
Sampling Frequency, Timing and Replication	18
Level of Change Detected for the Type of Sample Being Instituted.....	18

Contents (continued)

	Page
Field Methods	19
Field Preparations and Equipment Setup	19
Field Operations	19
Deploying Loggers at a New Site.....	20
Data Retrieval.....	21
Replacement of Loggers.....	21
Data Handling, Analysis and Reporting	23
Data Storage, Entry, Verification and Editing.....	23
Metadata Procedures	24
Database	24
Recommendations for Routine Data Summaries and Reporting.....	24
Annual Data Summary included in Coral Reef Monitoring Data Summary Reports.....	24
Early Warning of Temperature Related Stress	25
Data Shared Online.....	26
Data Archival Procedures.....	26
Data Analyses.....	26
Additional Analyses	27
Personnel Requirements and Training	29
Roles and Responsibilities.....	29
Qualifications	29
Training Procedures.....	30

Contents (continued)

	Page
Operational Requirements	31
Annual Workload and Field Schedule.....	31
Equipment Needs.....	32
Equipment	32
Support Equipment.....	32
Software.....	32
Startup Costs and Budget Considerations	34
Safety.....	35
Literature Cited	37
Appendix A. Sample Graphs and Tables from Graphing Templates	41

Figures

	Page
Figure 1. South Florida/Caribbean Network parks.	1
Figure 2. Virgin Islands National Park and St. John coral monitoring index sites, and Windspirit grounding site.	12
Figure 3. Buck Island Reef National Monument index sites.	13
Figure 4. Salt River Bay National Historic Park and Ecological Preserve index site showing locations for both sets of loggers.....	14
Figure 5. Biscayne National Park index sites.....	16
Figure 6. Dry Tortugas National Park extensive and index sites.	17
Figure 7. St. John, U.S. Virgin Islands water temperatures during 2005 coral bleaching event compared with historical data range (1990–2004).	25
Figure 8. HOBO® Water Temp Pro v2 logger, boot and cap.....	32
Figure A-1. Virgin Islands National Park water temperature summary graphs.....	42
Figure A-2. Virgin Islands National Park water temperature stress threshold graphs.....	43
Figure A-3. The current year’s water temperature for Virgin Islands National Park compared with 2005 (an extensive bleaching year) and the 1990–2004 range of daily average temperatures for all sites.....	44

Tables

	Page
Table 1. IRMA links to associated to standard operating procedures.....	xiii
Table 2. Site locations and descriptions [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; BISC—Biscayne National Park; DRTO—Dry Tortugas National Park.	7
Table 3. Linking field tasks to related SOPs.	20
Table 4. Data life cycle.	23
Table 5. Annual monitoring schedule [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; and DRTO—Dry Tortugas National Park.	31
Table 6. South Florida/Caribbean Network Budget.	34
Table A-1. Virgin Islands National Park water temperature data summary at coral monitoring sites.....	45

Standard Operating Procedures (SOPs)

The following standard operating procedures accompany the *Coral Reef Ecosystem Water Temperature Monitoring: Protocol Narrative Version—1.1* and are published separately.

Table 1. IRMA links to associated to standard operating procedures. Note these version numbers were current at the time of this narrative publication but may be revised in the future.

SOP Number	Title	Link to Published Document/IRMA Record
WT01	<i>Testing the Precision of HOBO® Loggers in a Cold Bath—Version 1.1</i>	2278932
WT02	<i>Launch HOBO® Temperature Pro v2 Logger—Version 1.1</i>	2278933
WT03	<i>HOBO® Temperature Pro v2 Field Data Collection using the HOBO® Waterproof Shuttle - U-DTW-1—Version 1.1</i>	2278934
WT04	<i>Deploying and Retrieving HOBO® Pro v2 Temperature Loggers—Version 1.1</i>	2278935
WT05	<i>*.hobo File Renaming Procedure, Conversion and Storage—Version 1.0</i>	2278936
WT06	<i>Entering Data into the Excel Field Log—Version 2.0</i>	2278937
WT07	<i>Import *.csv Files into Access Database</i>	Archived
WT08	<i>QA/QC of Newly Imported HOBO® Data Files into Aquarius—Version 2.0</i>	2278938
WT09	<i>Reports, Graphing, and Web Page Data—Version 2.0</i>	2278939
WT10	<i>Exporting Data to Everglades DataForEVER Database</i>	Archived
WT11	<i>Revising the Protocol—Version 1.1</i>	2278940
WT12	<i>Importing Data to Aquarius Database—Version 1.0</i>	2278941

Executive Summary

The Coral Reef Ecosystem Water Temperature Monitoring Protocol is a guide for the deployment, maintenance, and data management of South Florida/Caribbean Network (SFCN) temperature loggers. These loggers are currently deployed as part of a long-term coral reef monitoring program.

The three primary objectives for this monitoring protocol include:

1. Determine occurrence and duration of warm and cold water events that exceed thresholds known to cause stress (e.g., coral bleaching) to coral species for the purpose of interpreting trends in coral community metrics at sites established at Biscayne National Park (BISC), Buck Island Reef National Monument (BUIS), Dry Tortugas National Park (DRTO), Salt River National Historic Park and Ecological Preserve (SARI) and Virgin Islands National Park (VIIS).
2. Determine the status and trends in water temperatures at reef depth at coral monitoring sites established in Biscayne National Park, Buck Island Reef National Monument, Dry Tortugas National Park, Salt River National Historic Park and Ecological Preserve, and Virgin Islands National Park.
3. Assess any correlations of warm water events and/or cold water events with coral bleaching and/or disease outbreaks at sites established at Biscayne National Park, Buck Island Reef National Monument, Dry Tortugas National Park, Salt River National Historic Park and Ecological Preserve, and Virgin Islands National Park.

Temperature loggers are located at reef depth at a position generally representative of the site, typically at a centrally located coral reef monitoring transect pin. The exception to this logger placement is Salt River NHP&EP which has the greatest range of depths of any of the sites. In this case two locations were selected, one at a deep location and the second at a shallower location to better capture potential temperature differences. Most monitoring locations are between 2–20 meters (6.6–65.6 feet [ft]) depth but can reach 30-plus meters (98.4-plus ft) deep. Duplicate loggers are attached at the same point.

Water temperature has been historically collected as a basic parameter of water quality monitoring efforts at coral reef sites throughout the world. There are numerous references in scientific literature suggesting a link between water temperature anomalies and coral colony survivorship. Coral bleaching occurs when the coral host loses zooxanthellae from its tissue due to physiological stress, most often associated with high water temperatures and/or high incidence of solar radiation. Additionally, unusually cold water temperatures have been found to affect the survivorship of corals and other reef dwelling organisms. The National Park Service (NPS) and United States Geological Survey (USGS) have collected water temperature data around St. John and VIIS since 1990. This effort has expanded throughout the network, with 22 long-term in situ water temperature monitoring sites presently managed by the South Florida/Caribbean Network in Biscayne NP, Buck Island Reef NM, Dry Tortugas NP, Salt River NHP&EP, and Virgin Islands NP. In 2017, the initial Microsoft Access database developed for this protocol was retired in favor of Aquarius, the web-based NPS

repository for continuous water data. Data collected under this protocol will also be useful to NPS efforts outside the network such as the Climate Change Response Program's work to develop climate change strategies. This data also complements in situ seawater temperature data information collected by several partners throughout the Florida reef tract.

List of Acronyms

AM = Amanda's Reef

BB = Ball Buoy

BKN = Bird Key Reef North

BK= Bird Key Reef

BISC = Biscayne National Park

BUIS = Buck Island Reef National Monument

DRTO = Dry Tortugas National Park

EVER = Everglades National Park

FWRI = Florida Fish and Wildlife Research Institute

HA = Haulover Reef

IRMA = Integration of Resource Management Applications

JHA = Job Hazard Analysis

MB = Mennebeck Reef

MOCC = Motorboat Operator Certification Course

LH = Loggerhead Forest

NF = Newfound Reef

NOAA = National Oceanic and Atmospheric Administration

NRDT = Natural Resource Database Template

NPS = National Park Service

NPS FM4 = National Park Service, Field Manual 4

SARI = Salt River Bay National Historical Park & Ecological Preserve

SFR = South Fore Reef

SFCN = South Florida/Caribbean Network

SOP = Standard Operating Procedure

SV = Santa's Village Reef

TK = Tektite Reef

USGS = United States Geological Survey

USVI = United States Virgin Islands

VIIS = Virgin Islands National Park

WS = Windspirit Reef

WSG = Western Spur and Grove

YZ = Yawzi Reef

Background and Objectives

Rationale and Background

The South Florida/Caribbean Network (SFCN) of the National Park Service (NPS) Inventory & Monitoring (I&M) program is responsible for monitoring natural resources in seven South Florida and Caribbean national parks (Figure 1). “Marine Benthic Communities” were ranked as the highest priority “Vital Sign” for assessing the health and condition of SFCN parks (Patterson et al. 2008). The Coral Reef Ecosystem Water Temperature Protocol details the procedures for monitoring water temperature at coral monitoring sites, while a separate SFCN Coral Reef Monitoring Protocol (Miller et al. 2017) describes coral communities monitoring in network parks. Although tied to the other protocol, the technical equipment, field procedures, data management, QA/QC, and analysis procedures required are different enough to warrant this separate document. This protocol follows guidelines described in Oakley et al. (2003).

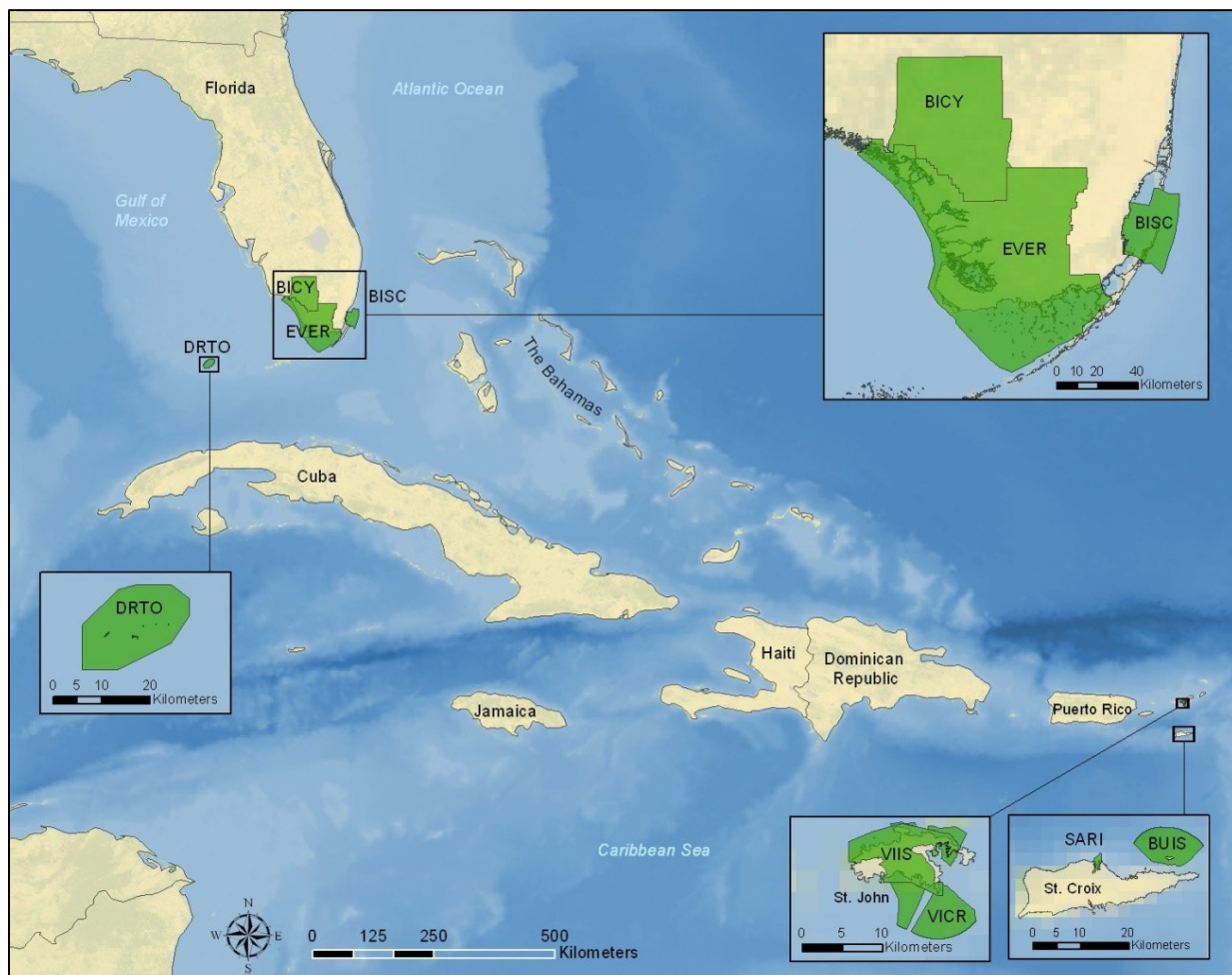


Figure 1. South Florida/Caribbean Network parks.

Water temperature has been historically collected as a basic parameter of water quality monitoring at coral reef sites throughout the world. Corals and many other marine organisms exist in a relatively narrow range of temperatures; coral stress and bleaching can occur outside this range. There are numerous references suggesting a link between water temperature anomalies and coral colony survivorship (e.g., Hoegh-Guldberg and Smith 1989; Glynn and D'Croz 1990; Brown 1997; Winter et al. 1998; Hoegh-Guldberg 1999; Rosenberg and Ben-Haim 2002; Miller et al. 2006; Whelan et al. 2007; Miller et al. 2009; Rogers et al. 2009; Lirman et al. 2011). Monitoring reef-depth temperature provides information on the intensity and duration of water temperature stress events, yielding better informed interpretation of trends in coral reef community metrics. In addition, such monitoring helps develop cause-and-effect hypotheses that allow management to better target research funding requests. For sites monitored during the summer (e.g., at Virgin Islands National Park), unusually warm temperatures may provide an early warning of potential bleaching events. This alerts park managers, and can trigger additional, episodic monitoring. The significance of water temperature monitoring has recently taken on a new dimension in helping to understand ecological dynamics associated with global climate change (Sowder and Steel 2012).

Reef water temperature is a key factor when trying to analyze long-term coral reef monitoring results and explore the relationship between coral bleaching and survival. Zooxanthellae are algae that reside within coral tissue and give healthy coral its coloration. When zooxanthellae are lost, the underlying calcium carbonate skeletal structure is seen through the transparent tissue of the coral, giving it the “bleached” appearance characteristic of the phenomenon. This symbiotic relationship is important because the coral host receives most of its nutrients from zooxanthellae. Bleaching is associated with physiological stress, most often related to high water temperatures and/or high incidence of solar radiation (Brown 1997; Hoegh-Guldberg 1999). Bleaching thresholds are species specific and vary regionally; however, researchers consistently report that bleaching conditions occur at temperatures of 1°C above average maximum monthly temperatures (Hoegh-Guldberg 1999; Miller et al. 2009; Donner et al. 2005). The South Florida/Caribbean Network utilizes theoretical bleaching thresholds of 29.5 °C (85.1°F) in the U.S Virgin Islands and 30.5 °C (86.9°F) in Florida. This is consistent with Manzello et al. (2007), who report temperature bleaching thresholds of 29.4 °C (84.9°F) for St. Croix and 30.5 °C (86.9°F) for the Florida Reef Tract.

Personal (in situ) observations along with these thresholds are used to guide monitoring activities with respect to potential bleaching events in SFCN parks. Additionally, unusually cold water temperature can cause bleaching and/or coral stress and has been found to affect the survivorship of corals, fish and other reef dwelling organisms (Mayer 1914; Davis 1982; Roberts et al. 1982; Jaap 1984; Lirman et al. 2011). The South Florida/Caribbean Network uses the 16°C (60.8°F) threshold reported in Lirman et al. (2011) to guide monitoring activities during cold water events in South Florida parks. There is no historical evidence of cold-water bleaching events in the United States Virgin Islands (USVI).

Water temperature loggers are deployed at reef depth as part of a long-term reef monitoring program that originally began in Virgin Islands NP in 1990. Reef depth is defined as the depth of the resource at a particular site. This contrasts with satellite sea surface temperature measurements collected by

the National Oceanic and Atmospheric Administration (NOAA) which measure the upper millimeters of the ocean. The South Florida/Caribbean Network currently conducts in situ water temperature monitoring at 22 locations throughout network parks. The network monitors benthic conditions at “index” sites, which are moderate to high coral cover reefs selected due to management interest or previous research work. The network also monitors “extensive” sites, which are randomly distributed throughout the park in coral reef habitat of at least 5% live stony coral cover. Currently the network monitors water temperature at 17 index site locations, four extensive site locations, and one historic grounding location in parks throughout the network.

A National Park Service employee, Larry McLain, first started monitoring water temperature data at Yawzi Reef (Virgin Islands NP) from 10 January 1988 to 12 April 1988 and then continuously from 27 December 1989. A temperature logger was installed at the Windspirit cruise ship grounding site on 26 February 1990. Data collection at Newfound Reef began 4 January 1991. Data has been collected nearly continuously at these three sites with occasional gaps, as the initial loggers had to be brought back to the office and downloaded before re-deployment. Water temperature monitoring increased concurrently with the addition of new coral monitoring sites. Data collection began with Ryan[®] RTM2000 temperature loggers. In 2003, the Ryan[®] loggers were replaced by HOBO[®] Water Temp Pro v1 data loggers. In 2005 the HOBO[®] v1 sensors were replaced with HOBO[®] v2 sensors. In late 2005, loggers began to be deployed in pairs at each sample site to provide redundancy in case of logger malfunction.

Water temperature data has already proven useful in evaluating changes in coral communities by showing trends of thermal stress on reefs over time. In 2005, a coral bleaching event associated with abnormally high temperatures in the northeast Caribbean included the South Florida/Caribbean Network’s USVI parks. Observations of wide-spread coral bleaching and elevated seawater temperatures triggered episodic monitoring that documented greater than 60% loss in coral cover at the USVI index monitoring sites from 2005–2007 (Miller et al. 2006; Miller et al. 2009). Analysis of the temperature and benthic monitoring data revealed temperature was positively correlated with coral bleaching. However, the majority of coral mortality was caused by a post-bleaching disease outbreak (Whelan et al. 2007; Miller et al. 2009). In 2010, warm water temperature again triggered episodic benthic monitoring. Additionally, temperature data from these two events helped define the effect of tropical weather systems (tropical waves, storms and hurricanes) on water temperature.

In this protocol, SFCN researchers have established standard operating procedures (SOPs) to ensure that data are collected, analyzed and stored properly, data consistency is maintained, and to provide for personnel safety.

Measurable Objectives

The three primary objectives for this monitoring protocol include:

1. Determine occurrence and duration of warm and cold water events that exceed thresholds known to cause stress (e.g., coral bleaching) to coral species for the purpose of interpreting trends in coral community metrics at sites established at Biscayne National Park, Buck Island Reef National Monument, Dry Tortugas National Park, Salt River National Historic Park and Ecological Preserve, and Virgin Islands National Park.
2. Determine the status and trends in water temperatures at reef depth at coral monitoring sites established in Biscayne NP, Buck Island Reef NM, Dry Tortugas NP, Salt River NHP&EP, and Virgin Islands NP.
3. Assess any correlations of warm water events and/or cold water events with coral bleaching and/or disease outbreaks at sites established at Biscayne NP, Buck Island Reef NM, Dry Tortugas NP, Salt River NHP&EP, and Virgin Islands NP.

Reef depth is defined as the depth of the resource at a particular site. The SFCN coral reef monitoring sites are typically between 2–20 meters (6.6–65.6 ft) depth but can reach 30-plus meters (98.4-plus ft) deep.

Sampling Design

Rationale for Selecting this Sampling Design over Others

Monitoring water temperature using data loggers placed in situ at reef depth provides data directly commensurate to documenting the stress experienced by coral reef ecosystem species. This approach is also efficient, cost-effective, and has low environmental impact.

Applicability to Coral Reef Monitoring

Sea surface measurements that occur with standard water quality sampling and satellite-generated data generally do not necessarily reflect benthic conditions. Satellites provide large area sea surface water temperatures and use passive multi-channel infrared measurements that correlate to water temperatures in the sea surface shallow water layer (0.1 millimeter [0.004 inches {in}] depth). Satellite observations are generally less frequent (e.g., twice per week) when compared to in situ loggers (every two hours). And satellite observations may be interrupted at critical times by atmospheric conditions such as storm clouds generated during tropical storms and hurricanes. Temperature measurements at reef depth are more representative of the water temperatures affecting the coral reef environment. Reef depth temperature monitoring is critical to connecting temperature changes with effects on benthic organisms. Co-locating data loggers at sites with benthic monitoring allows for combined analysis and establishment of potential linkages between water temperature and changes in these organisms. This monitoring provides efficient and relatively inexpensive data collection of a covariate that is important to understanding coral reef ecosystems.

Efficiency and Cost Effectiveness

Minimal person time is required for sensor deployment and retrieval as this occurs simultaneously with coral reef monitoring. Sensors have minimal cost (\$129.00 per sensor in 2020). The data sensors used have adequate precision (± 0.2 °C), simple operating procedures, and low maintenance requirements.

Very Low Environmental Impact

HOBO® Water Temp Pro loggers are made of inert material and only need to be downloaded periodically (typically annually), reducing the need for frequent site visits. Loggers are attached via cable ties to rebar, sand screws, or pins (used as part of the benthic monitoring protocol).

Site Selection and History

Water temperature is measured as a covariate indicator of reef stress at monitored reefs and site selection is dependent on the coral monitoring sampling design as described in SFCN's Coral Reef Monitoring Protocol (Miller et al. 2017). Water temperature data are collected at:

1. "Index sites," which are selected based upon management interest, historical work, or otherwise have considerable reef structure, coral cover, complexity and diversity. Smaller index sites consist of 20 randomly placed, permanently installed coral monitoring transects. Larger and/or deeper index sites use a two-stage design with sub-sites. Each sub-site is randomly placed within the larger area of interest and consists of four transects.

2. “Extensive sites,” which are smaller sites around 1,600 square meters (17,222 square feet [ft²]) in size, typically consisting of four permanent coral monitoring transects. Sites are randomly selected from a larger zone or area that is too large to effectively monitor using an index site approach.
3. “Windspirit,” a temperature monitoring only site established in 1990 in Virgin Islands National Park, at the site of a cruise ship grounding.

The population of interest for water temperature measurement is the water that comes in contact with the benthic community at the coral reef sites. At this scale of interest, one temperature sampling location per coral reef site is considered adequate to make this generalization, as differences in water temperature across the site are expected to be small relative to the daily and seasonal range of temperatures. Most monitoring sites have minimal depth change across the site; however at Tektite Reef the bottom slopes from 6 meters (19.7 ft) at the shallower end to 19 meters (62.3 ft) at the deepest transect. At Salt River National Historic Park and Ecological Preserve, the site transects range from 9 to 29 meters (29.5 to 95.1 ft) deep.

Initially one data logger was installed per monitoring site. From late 2005 onward, a second logger was gradually added to sites at the exact same position to provide data redundancy in case one logger is lost or malfunctions.

The loggers are located at reef depth at a position generally representative of the site. Specific logger locations vary by site but are generally on a transect pin, a pin specifically dedicated to the temperature loggers, Aquamap station attachment, or buoy station anchor. Duplicate loggers are attached at the same point and the location recorded. The exception is Salt River NHP&EP which has the greatest range of depths of any of the sites. In this case two locations were selected, one at a deep location and the second at a shallower location to better capture potential temperature differences.

Number and Location of Sampling Sites

One temperature station (two loggers) per site are located at the following locations: Virgin Islands National Park (5 index, 1 Windspirit), Buck Island Reef National Monument (3 index), Biscayne National Park (2 index) and Dry Tortugas National Park (3 index, 4 extensive). In Dry Tortugas NP, the Loggerhead Forest and Santa’s Village index sites each have an extra temperature station (2 total) due to the size of the reef area being monitored. There are also two temperature stations in Salt River NHP&EP (1 index), one shallow (SG) and one deep (WW). All temperature loggers currently deployed are HOBO® Water Temp Pro v2 loggers. Sites, locations, depths, and deployment dates are given in Table 2.

Table 2. Site locations and descriptions [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; BISC—Biscayne National Park; DRTO—Dry Tortugas National Park.

Park	Location Name	Station Name	First Deployed	Depth (ft)	Latitude	Longitude	Location Details	Status
VIIS	Yawzi Reef	VIIS_YZ	Jan 1988	40	18.31394	-64.72581	On dedicated concrete block/pin in reef for loggers	Active
VIIS	Windspirit Grounding	VIIS_WS	Feb 1990	38	18.36560	-64.76181	On dedicated pin in reef for loggers	Active
VIIS	Newfound Reef	VIIS_NF	Jan 1991	25	18.34919	-64.66807	On dedicated pin in reef for loggers	Active
VIIS	Haulover Reef	VIIS_HA	Aug 1998	27	18.35135	-64.67932	On dedicated pin in reef for loggers	Active
VIIS	Tektite Reef	VIIS_TK	Aug 2005	60	18.30965	-64.72326	Base Station 1 (B1); off reef edge in sand/seagrass	Active
VIIS	Mennebeck Reef	VIIS_MB	Oct 2005	43	18.35421	-64.68443	Base Station 1 (B1); off reef edge in sand/seagrass	Active
BUIS	Western Spur & Groove	BUIS_WSG	May 2001	28	17.79901	-64.63578	Base Station 1 (B1)	Active
BUIS	South Fore Reef	BUIS_SFR	Feb 2002	41	17.78530	-64.61010	Base Station 1 (B1)	Active
BUIS	Mesophotic Bar	BUIS_BAR	Apr 2017	100	17.80538	-64.76063	Site BAR_01, Transect #1, origin pin	Active
SARI	Salt River Canyon	SARI_SG	Apr 2012	33	17.78525	-64.76063	Transect #01, terminal pin – spur and groove section	Active
SARI	Salt River Canyon	SARI_WW	Apr 2012	96	17.78495	-64.75900	Transect #15, terminal pin – west wall	Active

* Inside RNA 50 (DRTO_I50) was renamed Loggerhead Forest 4 (LH04) in 2016

** Inside RNA 05 (DRTO_I05) was renamed Loggerhead Forest 5 (LH05) in 2016

Table 2 (continued). Site locations and descriptions [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; BISC—Biscayne National Park; DRTO—Dry Tortugas National Park.

Park	Location Name	Station Name	First Deployed	Depth (ft)	Latitude	Longitude	Location Details	Status
BISC	Ball Buoy	BISC_BB	Jun 2004	16	25.31831	-80.18425	Transect #2, origin pin	Active
BISC	Amanda's Reef	BISC_AM	Jun 2004	9	25.35185	-80.17801	Transect #19, origin pin	Active
DRTO	Bird Key Reef	DRTO_BK	Oct 2004	33	24.61172	-82.87065	Base Station 3 (B3)	Active
DRTO	Inside RNA 41	DRTO_I41	May 2008	45	24.60459	-82.93017	Center Pin	Active
DRTO	Inside RNA 44	DRTO_I44	May 2008	35	24.68693	-82.88318	Center Pin	Active
DRTO	Outside RNA 42	DRTO_O42	May 2008	65	24.57857	-82.96451	Center Pin	Active
DRTO	Outside RNA 72	DRTO_O72	May 2008	11	24.69558	-82.78990	Transect #3, origin pin	Active
DRTO	Loggerhead Forest 3	DRTO_LH03	Jun 2012	58	24.65984	-82.93415	Center Pin	Active
DRTO	Loggerhead Forest 4*	DRTO_LH04	May 2008	52	24.66236	-82.92743	Center Pin	Active
DRTO	Santa's Village Reef 1	DRTO_SV01	Jun 2012	58	24.72457	-82.81507	Center Pin	Active
DRTO	Santa's Village Reef 3	DRTO_SV03	Jun 2012	57	24.72239	-82.82832	Center Pin	Active
DRTO	Bird Key North Reef	DRTO_BKN	Jun 2005	37	24.61348	-82.86950	Base Station 1 (B1)	Removed Jul 2016
DRTO	Loggerhead Forest 1	DRTO_LH01	Jun 2012	55	24.66814	-82.92585	Center Pin	Removed Jun 2019
DRTO	Loggerhead Forest 2	DRTO_LH02	Jun 2012	57	24.66309	-82.93099	Center Pin	Removed Jun 2014

* Inside RNA 50 (DRTO_I50) was renamed Loggerhead Forest 4 (LH04) in 2016

** Inside RNA 05 (DRTO_I05) was renamed Loggerhead Forest 5 (LH05) in 2016

Table 2 (continued). Site locations and descriptions [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; BISC—Biscayne National Park; DRTO—Dry Tortugas National Park.

Park	Location Name	Station Name	First Deployed	Depth (ft)	Latitude	Longitude	Location Details	Status
DRTO	Loggerhead Forest 5**	DRTO_LH05	May 2008	57	24.66381	-82.92704	Center Pin	Removed Jun 2014
DRTO	Santa's Village Reef 2	DRTO_SV02	Jun 2012	54	24.72324	-82.82036	Center Pin	Removed Jun 2014
DRTO	Inside RNA 26	DRTO_I26	May 2008	13	24.68404	-82.89425	Center Pin	Removed Jun 2019
DRTO	Inside RNA 33	DRTO_I33	May 2008	45	24.69704	-82.90650	Center Pin	Removed Jun 2014
DRTO	Inside RNA 36	DRTO_I36	May 2008	32	24.70824	-82.86302	Center Pin	Removed Jun 2019
DRTO	Inside RNA 38	DRTO_I38	May 2008	45	24.65695	-82.92743	Center Pin	Removed Jun 2019
DRTO	Inside RNA 63	DRTO_I63	May 2008	40	24.70715	-82.88160	Center Pin	Removed Jun 2013
DRTO	Outside RNA 12	DRTO_O12	May 2008	13	24.70643	-82.83812	Center Pin	Removed Jun 2013
DRTO	Outside RNA 27	DRTO_O27	May 2008	13	24.70318	-82.84879	Center Pin	Removed Jun 2013
DRTO	Outside RNA 56	DRTO_O56	May 2008	44	24.72122	-82.80214	Transect #2, origin pin	Removed Jun 2019
DRTO	Outside RNA 82	DRTO_O82	May 2008	47	24.72231	-82.80926	Center Pin	Removed Jun 2019

* Inside RNA 50 (DRTO_I50) was renamed Loggerhead Forest 4 (LH04) in 2016

** Inside RNA 05 (DRTO_I05) was renamed Loggerhead Forest 5 (LH05) in 2016

Table 2 (continued). Site locations and descriptions [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; BISC—Biscayne National Park; DRTO—Dry Tortugas National Park.

Park	Location Name	Station Name	First Deployed	Depth (ft)	Latitude	Longitude	Location Details	Status
DRTO	Outside RNA 84	DRTO_O84	May 2008	43	24.57390	-82.92581	Transect #4, origin pin	Removed Jun 2019
DRTO	Outside RNA 92	DRTO_O92	May 2008	18	24.72231	-82.80926	Center Pin	Removed Jun 2013
DRTO	Outside RNA 94	DRTO_O94	May 2008	44	24.72158	-82.80689	Center Pin	Removed Jun 2019

* Inside RNA 50 (DRTO_I50) was renamed Loggerhead Forest 4 (LH04) in 2016

** Inside RNA 05 (DRTO_I05) was renamed Loggerhead Forest 5 (LH05) in 2016

Virgin Islands National Park (VIIS):

There are six current water temperature monitoring locations in Virgin Islands NP. Five are co-located with permanent index sites: Yawzi, Tektite, Newfound, Mennebeck, and Haulover. One additional water temperature monitoring location is at an historic grounding site named Windspirit. Although the Windspirit temperature logger is not co-located on a coral monitoring site, it provides a valuable connection to the understanding of the thermal stresses acting upon the other SFCN index sites due to its location on an exposed northwest facing reef slope. This location provides a unique data stream for in-situ temperatures brought by winter storms and significant north swell events. Windspirit loggers are uniquely positioned to capture those permutations as all other temperature recording locations are on the eastern side of the island or the south shore. Additionally, the temporal record at Windspirit (established 1990) provides one of the longest temperature data sets in the Caribbean region (second to Yawzi Reef). The unique location, resource-depth (as opposed to satellite sea surface temperature), and duration of these two sites, create data sources of unmatched value not only to the objectives of this protocol, but to NPS partners in the region. Having access to these data provides additional understanding of the thermal stresses that act upon the sites established by the South Florida/Caribbean Network in Virgin Islands NP.

Ryan[®] RTM2000 temperature loggers were installed at reef depth at Yawzi Point (YZ) in December 1989 following a pilot water temperature monitoring study in 1988. Water temperature monitoring began at Windspirit (WS) in February 1990, Newfound Bay (NF) in January 1991, and Haulover Bay (HA) in August 1998 (Figure 2). These loggers were later replaced with HOBO[®] loggers. Eventually two more sites were added: Tektite (TK) in August 2005 and Mennebeck (MB) in October 2005, using HOBO[®] loggers. In 2005, duplicate loggers were established at each site and attached to the same mounting location as the original sensor.

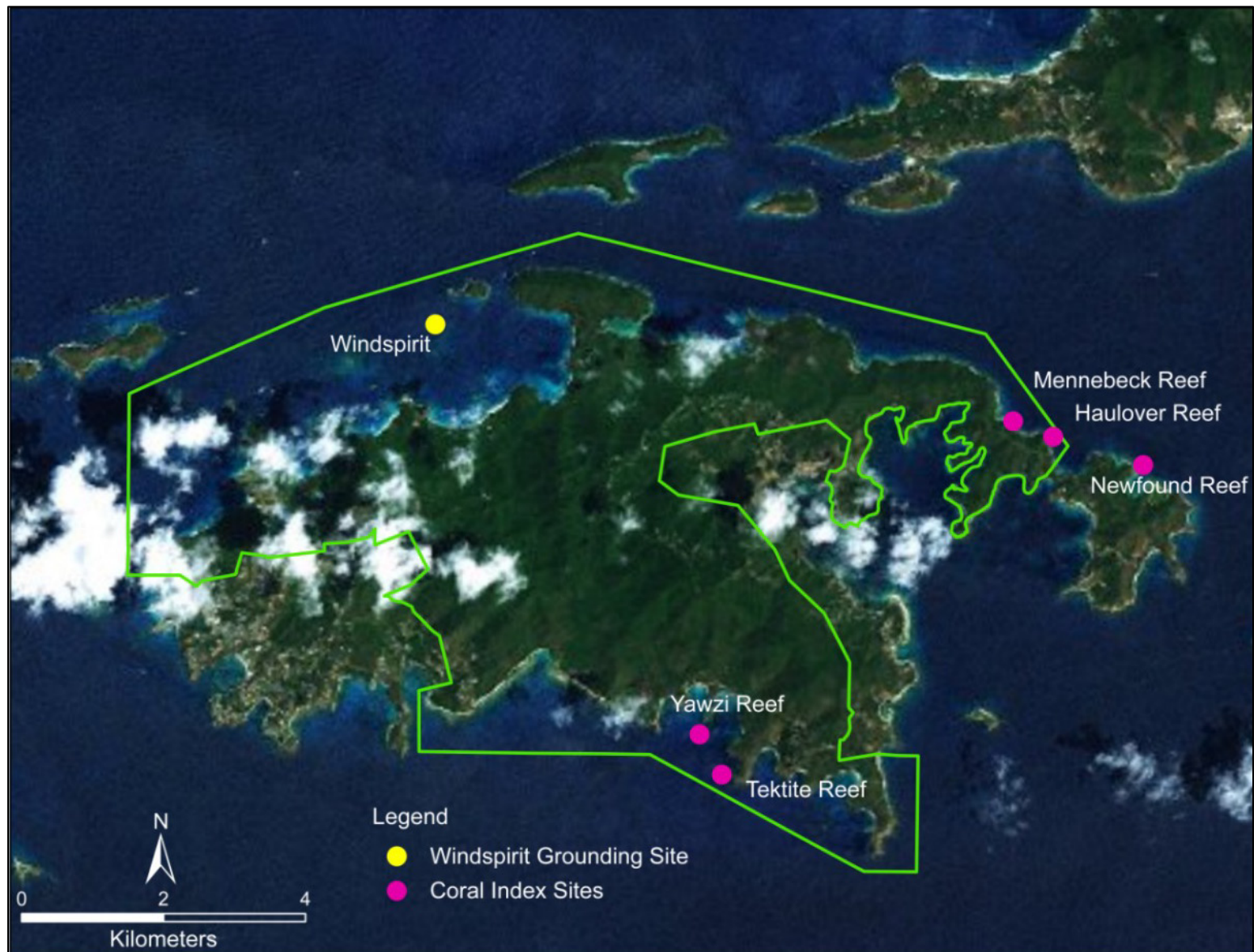


Figure 2. Virgin Islands National Park and St. John coral monitoring index sites, and Windspirit grounding site.

Buck Island Reef National Monument (BUI)

There are three current water temperature monitoring locations in Buck Island Reef NM co-located with coral monitoring sites: Western Spur and Groove (WSG), South Fore Reef (SFR), and the Mesophotic Bar (BAR; Figure 3). Water temperature monitoring began in 2001 and 2002 at WSG and SFR, respectively. The frequency of coral monitoring at WSG was reduced from annual to a five-year rotation in 2015, though temperature loggers are still located at the site and downloaded opportunistically when the South Florida/Caribbean Network monitors nearby sites. In 2017, the BAR coral monitoring site was established with four sub-sites.

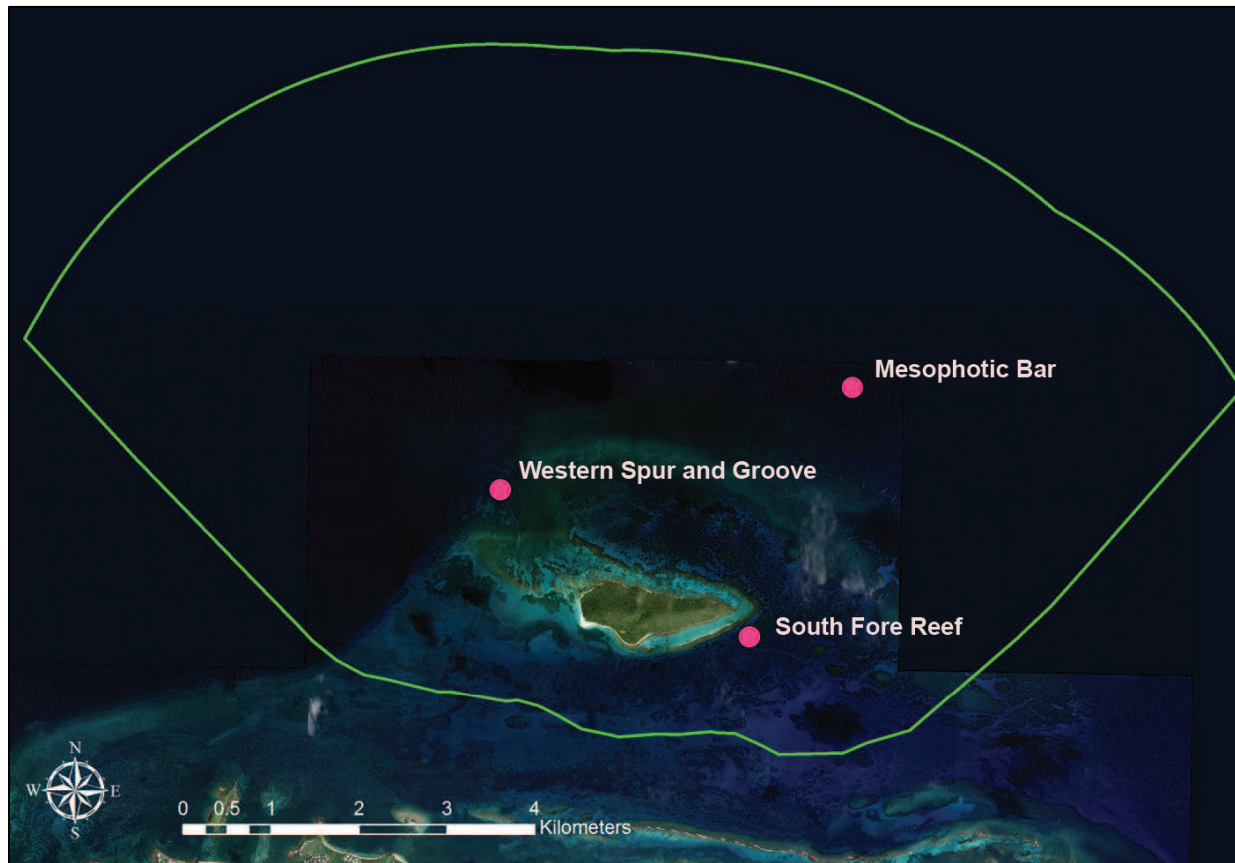


Figure 3. Buck Island Reef National Monument index sites.

Salt River Bay National Historic Park and Ecological Preserve (SARI)

Four HOBO® Water Temp Pro v2 loggers were installed in 2012, two at Spur and Groove (depth = 11 meters [36.1 ft]) and two at West Wall (depth = 28 meters [91.9 ft]; Figure 4). These loggers can help detect water temperatures variance due to the unique submarine canyon feature at Salt River Bay NHP&EP.



Figure 4. Salt River Bay National Historic Park and Ecological Preserve index site showing locations for both sets of loggers.

Biscayne National Park (BISC)

Two HOBO[®] Water Temp Pro v1 loggers per site were installed at Biscayne NP in 2005 (Figure 5) at Amanda's Reef (AM) and Ball Buoy (BB). These were replaced with two HOBO[®] Water Temp Pro v2 loggers per site in 2006.

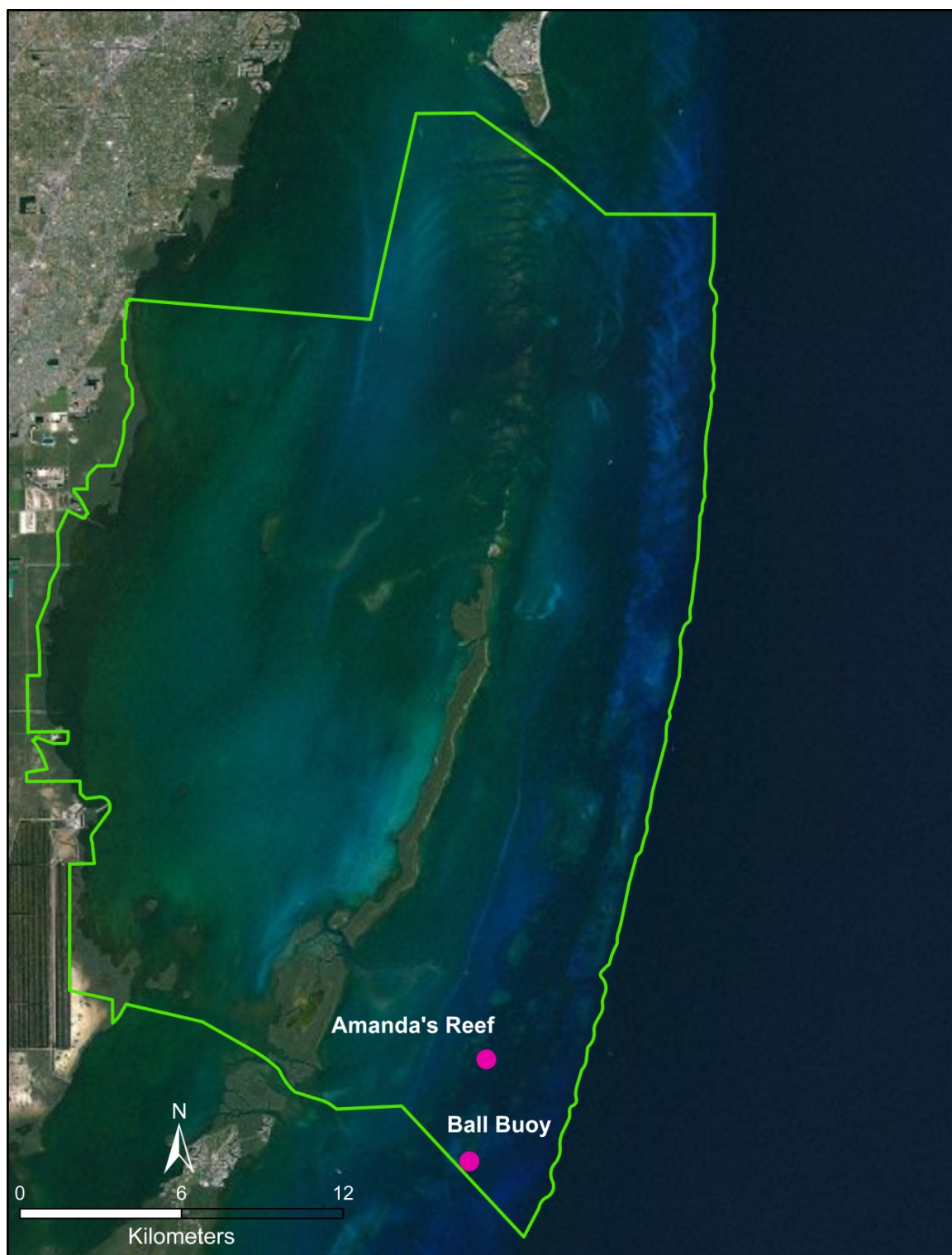


Figure 5. Biscayne National Park index sites.

Dry Tortugas National Park (DRTN)

Currently, there are nine active water temperature monitoring locations in Dry Tortugas NP: Bird Key (BK), two sub-sites of the Loggerhead Forest index site (LH-3 and LH-4), two sub-sites of the Santa's Village index site (SV-1 and SV-3), and four extensive sites (I-41, I-44, O-42, and O-72; Figure 6).

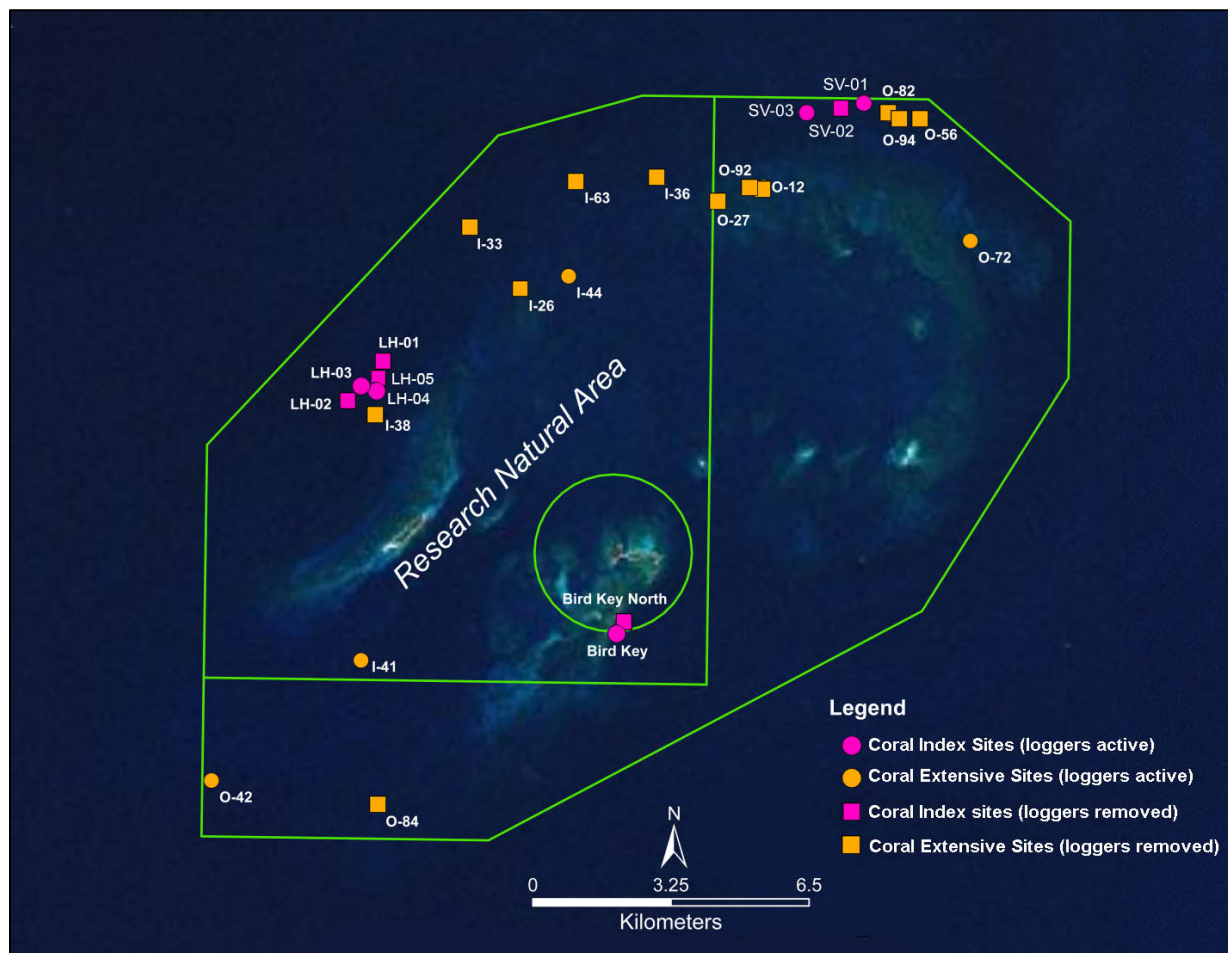


Figure 6. Dry Tortugas National Park extensive and index sites.

The South Florida/Caribbean Network began water temperature monitoring in 2005 at BK and Bird Key North (BKN). At each location, one HOBO® Water Temp Pro v1 logger per site was installed, and then replaced with two HOBO® Water Temp Pro v2 loggers per site in 2006. Coral monitoring was discontinued at BKN in 2012 in order to expand monitoring efforts at Loggerhead Forest and Santa's Village. Water temperature monitoring continued at BKN until 2016 when the loggers were permanently removed.

In 2008, the network established 18 park-wide coral reef “extensive” monitoring sites. Nine of the sites are located inside the Research Natural Area and nine outside. Two HOBO® Water Temp Pro v2 loggers were installed at each of the 18 extensive sites. In 2012, five of the extensive sites (O-12,

O-27, O-92, I-33, I-63) were discontinued from coral monitoring and temperature loggers were permanently removed as well. In 2019, it was determined that the amount of temperature monitoring in Dry Tortugas NP was excessive (26 locations at its peak) and loggers were permanently removed from all but four extensive sites (I-41, I-44, O-42, O-72). The network decided to continue water temperature monitoring at these specific sites because of their spatial distribution across the park.

In 2012, the network established two additional index sites in Dry Tortugas NP: Loggerhead Reef (LH) and Santa's Village (SV). The SV site consists of three sub-sites, each with four transects. Water temperature loggers were initially installed at each sub-site. In 2014, temperature monitoring was discontinued at SV-2 due to redundancy and proximity to other sub-sites.

The LH site consists of five sub-sites, each with four transects. Temperature loggers were co-located with each sub-site upon establishment. Three of these sub-sites were established in 2012 (LH-1, LH-2, and LH-3). The remaining two sub-sites were originally part of the extensive site monitoring that began in 2008 (I-50 and I-05 were renamed as LH-4 and LH-5, respectively), but were incorporated into the LH index site. In 2014, loggers were permanently removed from LH-2 and LH-5 because of redundancy and proximity to other sub-sites. In 2019, temperature monitoring at LH-1 was also discontinued. Temperature loggers are currently present at only two of the LH sub-sites (LH-3 and LH-4).

Sampling Frequency, Timing and Replication

HOBO[®] Water Temp Pro v2 sensors are continuously deployed, sampling at two-hour intervals. Two sensors are synchronized and deployed together at each site to provide redundancy. Temperature data from the two sensors are considered sub-samples and are averaged for analyses. Sensors are inspected and downloaded once a year, before impending hurricanes, or more frequently when a potential thermal stress event occurs.

Level of Change Detected for the Type of Sample Being Instituted

HOBO[®] Water Temp Pro v1 and v2 operation range is -20° to 50°C (-4° to 122°F) in water $\pm 0.2^{\circ}\text{C}$ with a resolution of 0.02°C (32.04°F) at 25°C (77°F). Typical analysis includes detection of unusual temperature patterns and comparison of mean seasonal or monthly temperatures to a baseline.

Field Methods

Field Preparations and Equipment Setup

Water temperature monitoring sites are co-located with coral monitoring sites (currently the South Florida/Caribbean Network monitors water temperature at 22 locations). Access to the sample sites are addressed in the SFCN coral reef monitoring protocol (Miller et al. 2017). No permits are required for SFCN staff to collect temperature data in any of the SFCN parks.

Field crews will review the field log before commencing field operations. A field log is maintained with specific information pertaining to each data logger. Serial number, date, time of deployment, logger program launch time, site identification, and any comments are recorded in this log. Depth and coordinates are recorded the first time the loggers are installed.

Replacement loggers will be available in case the deployed loggers fail or are missing. The HOBO[®] waterproof shuttle will be time-synchronized before going into the field.

When new loggers are to be deployed either at new sites or replacing those at existing sites, the accuracy of each logger is tested prior to field deployment as described in SOP WT01 *Testing the precision of HOBO[®] data loggers in a Cold Bath* (SFCN 2020a; see also Sowder and Steel 2012). Loggers with greater than 0.15°C difference from the average of the other loggers will not be deployed in the field. Most loggers tested will record values well within the error range, but any logger that records average values outside $\pm 0.15^{\circ}\text{C}$ will not be used, as deploying a logger with initial readings so close to an unacceptable threshold is not worth the loss of precision and the consequent QA/QC personnel time needed for the resulting data. Loggers with average values outside $\pm 0.2^{\circ}\text{C}$ can be returned to the manufacturer as faulty.

Field Operations

The loggers are placed in rubber boots and caps and installed at reef depth (2–30 meters [6.6–98.4 ft]); thus, direct sunlight should not bias temperature readings (Sowder and Steel 2012). Loggers are installed/downloaded/retrieved by a dive team and are attached to a coral community monitoring center pin, transect pin, Aquamap station attachment, or buoy station with zip ties. Monitoring occurs concurrently with coral reef community monitoring (Miller et al. 2017) and other member(s) of the dive team are implementing aspects of that protocol. Locations of loggers are provided in Table 1 with GPS coordinates. This information is also stored in the Microsoft Excel spreadsheet named “HOBO_Temperature_Field_Log.xlsx,” located here:

X:\SFCN\Vital_Signs\Marine_Benthic_communities\Water_Temperature\data. Three different types of operations typically occur: deploying loggers at a new site, data retrieval, and replacement of loggers. Standard operating procedures relating to each operation are shown in Table 3.

Table 3. Linking field tasks to related SOPs. SOP WT07 *Import *.csv Files into Access Database* and SOP WT10 *Exporting Data to the Everglades DataForEVER Database* are archived and no longer used.

Standard Operating Procedure	Deploy Loggers at New Site	Data Retrieval	Replacing Loggers at Existing Site
SOP WT01 <i>Testing the Precision of HOBO® Loggers in a Cold Bath—Version 1.1</i>	X	–	X
SOP WT02 <i>Launch HOBO® Temperature Pro v2 Logger—Version 1.1</i>	X	–	X
SOP WT03 <i>HOBO® Temperature Pro v2 Field Data Collection using the HOBO® Waterproof Shuttle - U-DTW-1—Version 1.1</i>	–	X	–
SOP WT04 <i>Deploying and retrieving HOBO® Temperature Pro v2 loggers—Version 1.1</i>	X	X	X
SOP WT05 <i>*.hobo File Renaming Procedure, Conversion and Storage—Version 1.0</i>	–	X	X
SOP WT06 <i>Entering Data into the Excel Field Log—Version 2.0</i>	X	X	X
SOP WT08 <i>QA/QC of Newly Imported HOBO® Data Files into Aquarius Database—Version 2.0</i>	–	X	X
SOP WT09 <i>Reports, Graphing and Web Page Data—Version 2.0</i>	–	X	X
SOP WT11 <i>Revising the Protocol—Version 1.1</i>	–	–	–
SOP WT12 <i>Exporting Data to Aquarius Database—Version 1.0</i>	–	X	X

Deploying Loggers at a New Site

Tested loggers (see above) are prepared for deployment in the field following the steps described in SOP WT02 *Launch HOBO® Temperature Pro v2 Logger* (SFCN 2020b). The deployment time is set to midnight. For example, if the logger is deployed on October 5, the first temperature reading is taken on October 6 at 12:00 a.m. Details of deploying the loggers are described in SOP WT04 *Deploying and Retrieving HOBO® Temperature Pro v2 Loggers* (SFCN 2020c). Specific logger location varies by site but is generally on a transect pin, a pin specifically dedicated to the temperature loggers, Aquamap station attachment, or buoy station anchor that will remain attached to the bottom in the case of storms and is easy to re-locate. The field log notebook is updated to include the new site's specific GPS coordinates, depth, and notes. This information is also entered into a Microsoft Excel spreadsheet named "HOBO_Temperature_Field_Log.xlsx," located here: *X:\SFCN\Vital_Signs\Marine_Benthic_communities\Water_Temperature\data* (see SOP WT06 *Entering Data into the Excel Field Log* [SFCN 2020d]).

Data Retrieval

There are two methods for downloading the data from the loggers: a HOBOTM waterproof shuttle is used to download the temperature data while submerged, or the logger is brought to the surface, and connected with the HOBOTM launcher/reader (attached to a laptop computer). The preferred method is to use the shuttle, as it prevents potential temperature spikes when the sensor is brought to the surface and reduces QA/QC time. When it is determined that data from the loggers should be downloaded, typically during annual coral reef monitoring, or episodically (during thermal stress event), the HOBOTM waterproof shuttle is used to transfer the data from the logger to the shuttle. This process involves unfastening the logger from the pin or other mounting structure, removing the protective boot and cap, inserting the logger into the shuttle and depressing a handle on the shuttle. When the data transfer is complete (generally < 1 minute), the logger is placed back in the boot and cap, then re-attached to the mounting structure with cable ties. This process is repeated for each of the paired loggers (See SOP WT03 *HOBOTM Temperature Pro v2 Field Data Collection using the HOBOTM Waterproof Shuttle – U-DTW-1* [SFCN 2020e] for more information and specific details on how to use the HOBOTM waterproof shuttle). When data are transferred to the shuttle from the logger, it is no longer contained on the logger. The logger will begin recording again at the next scheduled interval leaving no gap in the data stream. Care must be used with the shuttle as it is positively buoyant and can easily float away from divers, and until data are transferred from the shuttle to another device (laptop or server) it is the only location where the data exists. Attaching a stainless steel clip to the shuttle makes it easier to carry on dive gear and also makes it negatively buoyant to prevent it from floating away.

If the underwater shuttle malfunctions, data can also be downloaded from the loggers by bringing them to the surface and downloading them via the HOBOTM OpticTM USB Base Station, then re-deploying them. Procedures are detailed in SOP WT04 (SFCN 2020c). The deployment time is set to the next midnight.

The field log notebook is maintained with information recorded during every visit, and this information is also entered into the Microsoft Excel spreadsheet named “HOBOTM_Temperature_Field_Log.xlsx,” located here:

X:\SFCN\Vital_Signs\Marine_Benthic_communities\Water_Temperature\data.

If a logger is lost, e.g. disappears during a hurricane, this is noted in the field log notebook and a replacement logger is deployed.

Replacement of Loggers

Replacement of loggers involves a combination of data retrieval from the old logger and deployment steps for new loggers outlined above. Steps are detailed in SOP WT04 (SFCN 2020c). When retrieving loggers either for replacement with new loggers or because of a need to update software, they are preferably downloaded with the HOBOTM waterproof shuttle before retrieving them to the surface. This will save QA/QC time by preventing post-deployment temperature records and minimizing the loss of data if a logger accidentally floats away. However, in the event the logger must be downloaded out of the water, the HOBOTM OpticTM USB Base Station can be used.

Data Handling, Analysis and Reporting

Data Storage, Entry, Verification and Editing

The data life cycle is described in Table 4.

Table 4. Data life cycle.

Activity	Date
Field data collection	Coincides with coral monitoring site schedule
File storage on server Scanning of field logbook	Afternoon or day after field data collection
Data conversion & import into database	Week after field data collection
Data QA/QC'd	Month after field data collection
Resource Brief Data made publicly available Archiving	December

Data that are downloaded in the field with the shuttle can be stored temporarily on the shuttle, or transferred to a field laptop computer (e.g., when in remote locations such as Dry Tortugas NP), until transferred to the SFCN Florida server. Original and exported data files are stored under their appropriate Park_Site name folder in:

Z:\SFCN\Vital_Signs\Coral_Reef_Water_Temperature\data\Sites

In the VIIS office data are stored in:

X:\SFCN\Vital_Signs\Marine_Benthic_communities\Water_Temperature\data\Sites.

In 2018, the South Florida/Caribbean Network transitioned from using a local Microsoft Access database for water temperature data storage to a national NPS water quality database named Aquarius. Aquarius is a server-based platform managed by the NPS Water Resources Division and where all SFCN water temperature data are now stored. Data are exported using HOBOWare® Pro software, then converted to *.csv file format for uploading into the Aquarius database using SOP WT05 **.hobo File Renaming Procedure, Conversion, and Storage* (SFCN 2020f). Data from the Field Logbook are entered into the database using SOP WT06 *Entering Data into the Excel Field Log* (SFCN 2020d). Since the transition from Access to Aquarius, SOP WT07 *Import *.csv Files into Access Database* is obsolete and now archived. Instead, SOP WT12 *Import *.csv Files into Aquarius Database* (SFCN 2020g) describes how to upload files into the Aquarius database. Once data have been uploaded into the database, the *.hobo and *.csv files are moved to an Archive folder within that park site folder, making it easy to see files that remain to be uploaded.

The QA/QC procedures are performed once data are uploaded into Aquarius as described in SOP WT08 *QA/QC of Newly Imported HOBOWare® Data Files into Aquarius Database* (SFCN 2020h). The data from the co-located loggers at a site should mirror each other. Any differences greater than

0.3°C are investigated. This is presently done by comparing the individual values in the CSV file in Microsoft Excel with an R-script. When data do not meet QA/QC standards, steps are described to invalidate that data. The following errors are checked for:

- The logger was collecting data pre-deployment or post-retrieval
- Logger malfunctions such as time drift, temperature drift, missing data, sensor gives same value continuously, or data out of range.
- Data gaps where data are missing, possibly because a file was not uploaded.

All data are reviewed for QA/QC and proper data storage. Procedures developed for this step are consistent with recommendations in Sowder and Steel (2012). Once data have been validated, they are submitted to the network data manager for archiving and storage as outlined below in the Data Handling, Analysis, and Reporting section.

The logbook will be periodically scanned and the copies will be placed in the following location:
Z:\SFCN\Vital_Signs\Coral_Reef_Water_Temperature\data\field_logbook

Metadata Procedures

Metadata for the spatial location of sample sites and for each sensor deployment are stored in the Excel spreadsheet named “HOBOTemperature_Field_Log.xlsx”. General deployment site metadata such as coordinates and water depth are stored within the Aquarius system. Metadata requirements are further discussed in section 8.3 of the network data management plan (Witcher 2007).

Database

For a number of years, SFCN’s water temperature data were stored in a Microsoft Access database. This database was retired in 2018 and all data were transferred to the Aquarius Time-Series database which is maintained by the NPS Water Resources Division in Fort Collins, Colorado.

Recommendations for Routine Data Summaries and Reporting

The data will be used in several different types of reports and analyses such as:

1. Annual resource briefs included as part of the SFCN Coral Reef Monitoring Protocol data
2. Early warning communication of a coral bleaching episode
3. Live data on the Aquarius Web Data Portal
4. Annual data saved to IRMA and linked to from the SFCN website

Annual Data Summary included in Coral Reef Monitoring Data Summary Reports

An annual data summary by park across and within sites of daily mean, variance, maximum and minimum water temperature will be completed, coupled with graphs for the past two years and the entire data series. Daily average water temperature datasets for each park are created by averaging all valid data (including sensor 1 and sensor 2) from a particular site using the aggregate function in R.

These data are tied to the coral reef monitoring protocol reporting schedule and will be reported as part of the SFCN Coral Reef Monitoring Protocol park data summary reports. The number of days with average temperatures above the regional bleaching threshold as well as occurrence and duration

of any abnormal cold-water events are also reported. The SOP WT09 *Reports, Graphing, and Web Page Data* (SFCN 2020i) describes the procedures for exporting data from Aquarius into park specific graphing templates to create data summaries to be completed by December of each sampling year. Sample graphs are provided in Appendix A.

Early Warning of Temperature Related Stress

When conditions develop suggesting that coral bleaching or other stress may occur (e.g., Figure 7), the loggers may be downloaded more frequently to determine if surface level temperatures measured by satellite and surface buoys are also occurring at reef depth. Current logger data can easily be compared against historical data. If bleaching seems likely, park staff can be alerted to report signs of bleaching and additional monitoring may be triggered. In such cases data may be used to better assess associations between temperatures and severity/duration of coral bleaching, disease and other signs of stress on reefs. Well informed park staff can readily answer questions from the public. The graphing templates used in the annual summary report can be used and results rapidly shared with the parks involved.

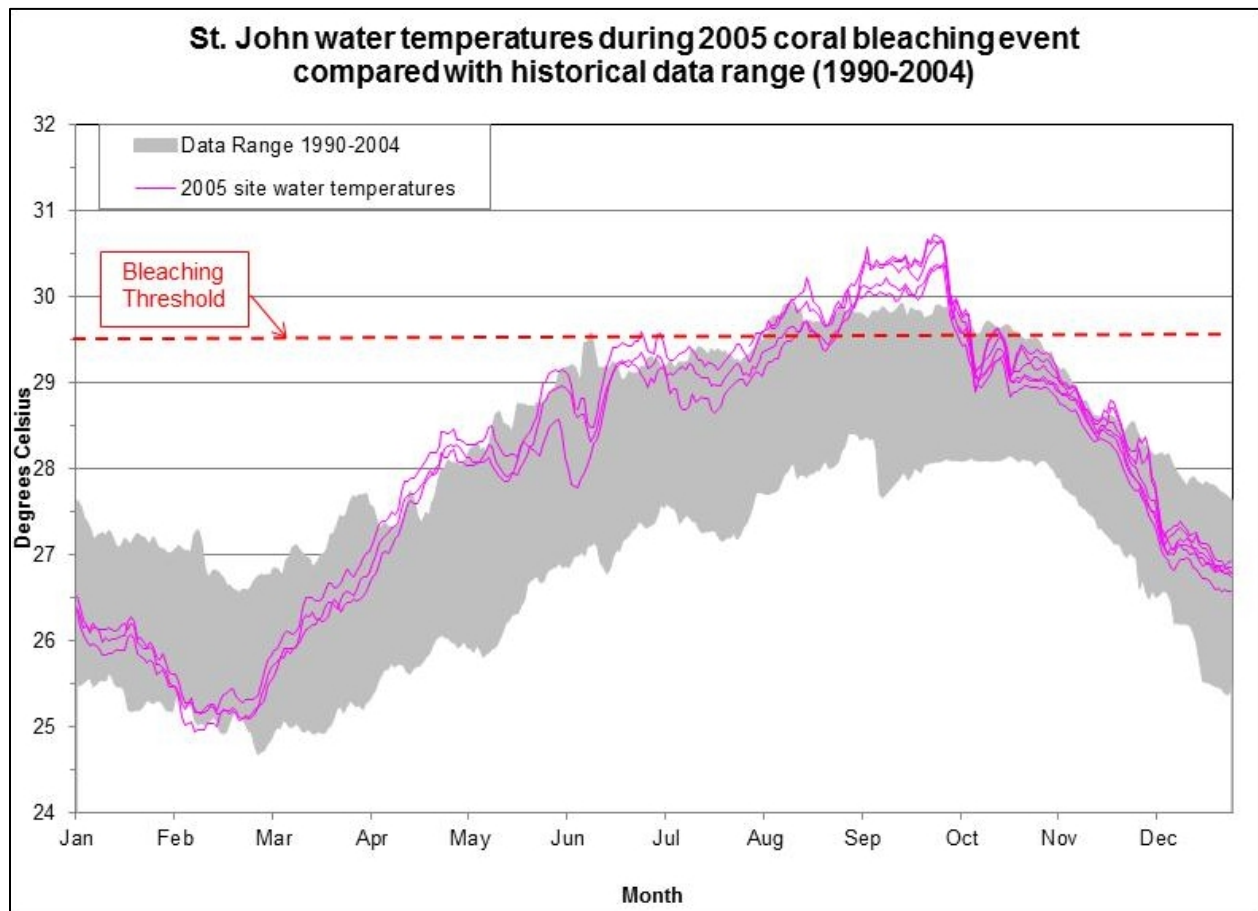


Figure 7. St. John, U.S. Virgin Islands water temperatures during 2005 coral bleaching event compared with historical data range (1990–2004). Data collected during spring and summer showed water temperatures at or exceeding historical maximums, triggering additional field visits and logger data downloads to determine if a coral bleaching event was likely to occur.

Data Shared Online

After data are uploaded into Aquarius and reviewed for QA/QC, the data are automatically available in the Aquarius web data portal at <https://irma.nps.gov/aqwebportal/>. Water temperature data are not considered sensitive and thus will be made publicly available. The SFCN Coral Reef Water Temperature web page maintains links to archived versions that are available on the IRMA Data Store. Details are described in the SOP WT09 (SFCN 2020i).

Data Archival Procedures

Annual archiving is started once the project manager has conducted the appropriate QA/QC procedures for a specific field season and has notified the network data manager that the dataset is ready for archiving. This occurs at the end of the calendar year. At this point the network data manager downloads a full export of all the temperature data, along with data gap information and notes, creates a zip archive, and uploads it to the IRMA Data Store. File access will be set to public unless access is restricted by a park protected data memo.

Once the data are archived, any changes made to the data are documented in an edit log. Secure data archiving is essential for protecting data files from corruption.

Backup copies of the data are maintained at the South Florida office and at the National Park Service office in Fort Collins, Colorado. For further detail of the archiving procedure please refer to the SFCN Data Management Plan (Witcher 2007).

Data Analyses

Annual data summaries may consist of calculating the following:

- Average, maximum, and minimum daily temperature
- Average of cold months (December of previous year–March)
- Average of warm months (July–October)
- Number of days average daily temperature greater than bleaching threshold (29.5°C [85.1°F] in U.S. Virgin Islands, 30.5°C [86.9°F] in South Florida)
- Number of days average daily temperature less than cold stress threshold (16°C [60.8°F] in South Florida; not recorded in U.S. Virgin Islands)
- Sum (average daily temperature – bleaching threshold) for all days above the threshold.
- Number of consecutive days where average daily temperature is greater than bleaching threshold.

Graphical summaries show annual water temperatures compared with previous years and overlaid on the historical data range of temperatures in non-bleaching years (e.g., Figure 7). Examples of tables and graphs are provided in Appendix A.

Additional Analyses

With a 30-plus year data set at St. John, Virgin Islands, long-term trends in annual, summer, and winter water temperatures are possible, but these analyses are not described in this protocol. Users for this purpose should be aware there are data gaps at the various sites. Most data gaps are short and have at least one other nearby site collecting data and thus most gaps (but not all) can be filled using data interpolation.

Personnel Requirements and Training

Roles and Responsibilities

The field portion of this protocol falls under the overall responsibility of the SFCN marine ecologist, although in the Virgin Islands it is managed regionally by the SFCN fisheries biologist. These procedures can be implemented by any dive team member. The SFCN marine ecologist is responsible for overseeing the entering of the data into the Aquarius database, conducting the QA/QC, and completing necessary analyses, but these tasks are typically delegated to one of the Florida-based biological science technicians. The SFCN data manager and assistant data manager are responsible for managing the data including archiving annual data sets, maintaining connectivity with the graphing templates, and assisting with analysis and reports. The SFCN marine ecologist is responsible for producing the SFCN coral reef monitoring reports which include the water temperature results.

Personnel assigned to data collection, analysis and storage shall be properly trained in the procedures relevant to the assigned tasks. Responsibility of proper adherence to procedure, quality control and quality assurance rests with all pertinent personnel.

Rules and regulations applicable to the performance of these tasks shall be observed, with particular note to individual park policies.

Nothing in this protocol implies or is meant to imply deviations from established federal, departmental or local safety rules and regulations applicable to the performance of assigned tasks. It is the responsibility of each individual to be familiar with such rules and regulations.

Qualifications

The following qualifications are accepted minimum standards to perform relevant procedures. Tasks may be performed by personnel in training status under the supervision of properly qualified persons. Specific guidelines and applicable regulations shall be strictly adhered to at all times. This list is not meant to be all inclusive and may be supplemented by individual park regulations and qualification requirements.

- NPS Blue Card Diver (Ref NPS FM4, 485 DM 27)
- DOI Motorboat Operator Certification Course (MOCC) (ref 36 CFR part 3, 485 DM 22) (necessary if driving an NPS boat)

Training Procedures

Personnel will thoroughly review this protocol before implementing procedures under the supervision of experienced staff. In addition to the protocol, personnel must complete the necessary requirements to maintain their NPS Blue Card for divers and at least one person on the boat must have a valid DOI MOCC certificate.

There are no restrictions to training in any procedure that does not entail diving or boating activities by the trainee. Nevertheless, trainees shall not be allowed to perform tasks unless under supervision. Divers in training and boat operator trainees shall perform under the supervision of qualified personnel and subject to pertinent regulations.

Operational Requirements

Annual Workload and Field Schedule

Field visits shall coincide with concurrent coral reef monitoring efforts unless periodic events dictate otherwise. Monitoring is conducted throughout the year with suggested months for field activities listed as target dates (Table 5). Some flexibility is allowed for logistics, safety, and to provide good field conditions for coral videography. If time and safety permit, additional logger downloads may occur before and during coral thermal stress events (early warning and event reporting) and before approach of tropical storms (to prevent data loss).

Table 5. Annual monitoring schedule [VIIS—Virgin Islands National Park; BUIS—Buck Island Reef National Monument; SARI—Salt River Bay National Historical Park and Ecological Preserve; and DRT0—Dry Tortugas National Park.

Month	Park	Site
January	VIIS	Haulover
February	BUIS	South Fore Reef
March	VIIS	Newfound
April	BUIS	Western Spur and Groove (every 5 yrs)
April	BUIS	Mesophotic Bar
April	SARI	Salt River
June	DRT0	Bird Key, Loggerhead Forest, Santa's Village
June	DRT0	Extensive sites (every 3 yrs)
September	BISC	Ball Buoy
September	BISC	Amanda's Reef
September	VIIS	Yawzi
September	VIIS	Tektite
October	VIIS	Mennebeck

The SFCN marine ecologist is responsible for the implementation of this protocol but may delegate tasks as needed. A two-person dive team is the minimum required for field work; for both boat and diving safety, and data collection. However, boating/diving personnel requirements can vary by park unit, so ensure all requirements for individual park units are reviewed and followed prior to data collection. The personnel required to implement this protocol include a team member from the Marine Ecology group with a corresponding effort by Data Management.

Equipment Needs

Equipment

- HOBO® underwater shuttle and/or launcher/reader connected to a laptop or workstation
- HOBO® Logger with removable rubber boot/cap
- Cable ties
- Knife or shears for cutting cable ties
- Field logbook

Support Equipment

- Standard dive equipment and accessories
- Boat with dive and boating safety equipment
- Navigation equipment and accessories (e.g., GPS, maps, charts)

Software

- HOBOWare software
- Aquarius – The Natural Resource Specialist for Information Management (Dean Tucker at the time of this writing) with the NPS Water Resource Division will need to be contacted in order to set up the Aquarius server and software. The SFCN data manager and/or assistant data manager can assist with setup.
- Microsoft Excel

A HOBO® underwater shuttle or launcher/reader connected to a laptop or workstation allows data transfer from the loggers. Each logger is encased in a removable rubber boot/cap (Figure 8), and loggers are attached with cable ties to pins or stakes. All sites are accessible by boat, but logger download, installation, or removal at each site must be done using SCUBA equipment.

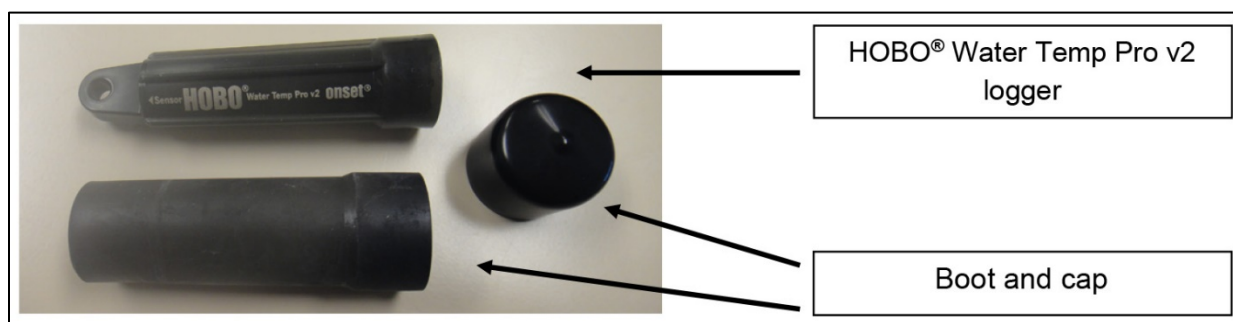


Figure 8. HOBO® Water Temp Pro v2 logger, boot and cap.

HOBO® Water Temp Pro v2 loggers have 12-bit measurement resolution and a precision sensor with $\pm 0.2^{\circ}\text{C}$ over a wide range. The loggers have a streamlined case for extended deployment in fresh or salt water, and are equipped with an optic interface for data offload in the field.

- Measurement Range: -20° to 50°C (-4° to 122°F) in water; -20° to 70°C (-4° to 158°F) in air
- Waterproof: to 120 meters (400 ft.)
- Accuracy: $\pm 0.2^{\circ}\text{C}$ at 0 to 50°C ($\pm 0.36^{\circ}\text{F}$ at 32° to 122°F)
- Resolution: 0.02°C at 25°C (0.04°F at 77°F)

The manufacturer estimates the battery life for the HOBO® data loggers at approximately six years based on a logging interval of one minute or longer. This protocol suggests replacement after five years as a conservative measure to prevent any data loss. If an unforeseen event prevents a logger from being replaced after five years, when the site is revisited the following year, the logger would still be within the six-year replacement schedule recommended by the manufacturer.

Startup Costs and Budget Considerations

The only costs in addition to those described in the SFCN Coral Monitoring Protocol (Miller et al. 2017) are described below. Equipment costs are based on prices in 2020 and are as follows:

- HOBO® Water Temp Pro v2 logger: \$129.00. Note that Onset®, the company that makes the loggers, offers a program to replace loggers at a reduced cost. At the time of this writing, customer service can be contacted and if you provide the serial number of a ‘retired’ logger, they will replace it at the reduced cost of \$95.00.
- Rubber boot/cap: \$20.00
- HOBO® Optic USB Base Station (BASE-U-4): \$124.00
- HOBO® Waterproof Shuttle (U-DTW-1): \$249.00

Table 6. South Florida/Caribbean Network Budget. **Note:** These are only additional expenses and do not include other operational expenses necessary to maintain a functional marine monitoring and dive program, e.g., boat, trailer, tow vehicle, equipment and maintenance, dive equipment, dive physicals, training, gas, computers, software, and travel. Costs are estimates (2020 dollars).

Category	Sub-Category	Costs (FY 2020, in USD)	Notes
Personnel	SFCN Marine Ecologist	\$2,650	0.02 FTE GS-12
	SFCN Biological Technician	\$1,520	0.02 FTE GS-7
	SFCN Assistant Data Manager	\$1,650	0.02 FTE GS-9
	Total Personnel Costs	\$5,820	—
Equipment & Supplies	HOBO Waterproof Shuttle (2 x \$249)	\$498	Start-up. Replace only as needed.
	HOBO Water Temp Pro v2 Logger (44 x \$129)	\$5,676	Start-up. Replace every 5-yrs. \$95/each with replacement program
	HOBO Rubber boot/cap (44 x \$20)	\$880	Start-up. Replace only as needed.
	Total Equipment Costs	\$7,054	—
Travel	—	\$0	No specific travel for water temperature. Collected during coral monitoring.
	Total Travel Costs	\$0	—
Total Protocol Implementation Cost	—	\$12,874	—

Safety

Personnel must review the respective SOP associated with operation of each SFCN vessel, Float Plan Safety Sheet, and any other SOPs associated with this protocol. They must also review and sign all Job Hazard Analyses (JHA) associated with this protocol. These SOPs and JHAs are located in the SFCN Safety SOP & JHA Binder. Electronic versions are available on the SFCN server at Z:\SAFETY\SFCN_SOPs_with_JHAs\Marine_operations.

Nothing in this protocol implies or is meant to imply deviations from established federal, departmental or local safety rules and regulations applicable to the performance of assigned tasks. It is the responsibility of each individual to be familiar with such rules and regulations.

Personnel must follow all rules, regulations, requirements, policies, and procedures from the NPS Dive Program, any park specific requirements, and any other requirements of the National Park Service not otherwise specified herein. All NPS-SFCN personnel will follow the Safe Practices Manual and Emergency Operations Plan specific to the respective park they are operating within. Dive team roles and responsibilities as predicated in NPS Field Manual 4 (NPS 2019) will be reviewed in a safety briefing before each dive trip.

Completion of the Department of Interior's Motorboat Operator Certification Course (MOCC) is required for the solo operation of an NPS vessel. Non-certified MOCC personnel may drive a park boat under the supervision of an MOCC certified operator. All SFCN vessels operate using state-of-the-art GPS chart plotters to ensure safe and efficient navigation.

Literature Cited

- 36 C. F. R. § 3. 2007. Boating and Water Use Activities. Title 36 Code of Federal Regulations, Part 3. Government Printing Office, Washington, D.C.
- 485 D. M. § 22. 2011. Watercraft Safety. Department of Interior Departmental Manual, Part 485, Chapter 22. Office of Occupational Safety and Health, Washington, D.C.
- 485 D.M. § 27. 1999. Underwater Diving Safety. Department of the Interior Departmental Manual, Part 485, Chapter 27. Office of Managing Risk and Public Safety, Washington, D.C.
- Brown, B. E. 1997. Coral Bleaching: Causes and consequences. *Coral Reefs* 16:S129–S138.
- Davis, G. E. 1982. A century of natural change in coral distribution at the Dry Tortugas: a comparison of reef maps from 1881 and 1976. *Bulletin of Marine Science* 32(2):608–623.
- Donner, S. D., W. J. Skirving, C. M. Little, M. Oppenheimer and O. Hoegh-Guldberg. 2005. Global assessment of coral bleaching and required rates of adaptation under climate change. *Global Change Biology* 11:1–15.
- Glynn, P. W. and L. D’Croz. 1990. Experimental evidence for high temperature stress as the cause of El-Niño coincident coral mortality. *Coral Reefs* 8:181–191.
- Hoegh-Guldberg, O. 1999. Climate change, coral bleaching and the future of the world’s coral reefs. *Journal of Marine and Freshwater Resources* 50:939–866.
- Hoegh-Guldberg, O. and G. J. Smith. 1989. The effect of sudden changes in temperature, light and salinity on the population density and export of zooxanthellae from the reef corals *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana. *Journal of Experimental Marine Biology and Ecology* 129:279–303.
- Jaap, W. C. 1984. The ecology of the South Florida coral reefs: a community profile. FWS/OBS – 82/08. MMS 84-0038. Minerals Management Service, Metairie, Louisiana.
- Lirman, D., S. Schopmeyer, D. Manzello, L. J. Gramer, W. F. Precht, F. Muller-Karger, K. Banks, B. Barnes, E. Bartels, A. Bourque, J. Byrne, S. Donahue, J. Duquesnel, L. Fisher, D. Gilliam, J. Hendee, M. Johnson, K. Maxwell, E. McDevitt, J. Monty, D. Rueda, R. Ruzicka and S. Thanner. 2011. Severe 2010 cold-water event caused unprecedented mortality to corals of the Florida Reef tract and reversed previous survivorship patterns. *Public Library of Science One*. 6(8): e23047. doi:10.1371/journal.pone.0023047.
- Manzello, D. P., R. Berkelmans and J. C. Hendee. 2007. Coral bleaching indices and thresholds for the Florida Reef Tract, Bahamas, and St. Croix, US Virgin Islands. *Marine Pollution Bulletin* 54(12):1923–1931.

- Mayer, A. G. 1914. The effects of temperature on tropical marine animals. Papers from the Tortugas Laboratory of the Carnegie Institution of Washington 6:1–24.
- Miller, J., C. S. Rogers, M. W. Feeley, A. J. Atkinson, A. D. Davis, M. E. Patterson, R. J. Waara, B. D. Witcher, J. M. Patterson, and E. M. Muller. 2017. Coral reef monitoring: Protocol narrative—Version 2.0. Natural Resource Report NPS/SFCN/NRR—2017/1464. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2240837> (last accessed November 2020).
- Miller, J., R. Waara, E. Muller, and C. Rogers. 2006. Coral Bleaching and disease combine to cause extensive mortality on reefs in US Virgin Islands. *Coral Reefs* 25:418.
- Miller, J., E. Muller, C. Rogers, R. Waara, A. Atkinson, K. R. T. Whelan, M. Patterson, and B. Witcher. 2009. Coral disease following massive bleaching in 2005 causes 60% decline in coral cover on reefs in the US Virgin Islands. *Coral Reefs* 28:925–937.
- National Park Service (NPS). 2019. Diving Management Field Manual FM4. National Park Service, Fort Collins, Colorado.
- Oakley, K. L., L. P. Thomas and S. G. Fancy. 2003. Guidelines for long-term monitoring protocols. *Wildlife Society Bulletin* 31(4):1000–1003.
- Patterson, M. E., A. J. Atkinson, B. D. Witcher, K. R. T. Whelan, W. J. Miller, R. J. Waara, J. M. Patterson, B. I. Ruttenberg, A. D. Davis, R. Urgelles, R. B. Shamblin. 2008. South Florida / Caribbean Network vital signs monitoring plan. Natural Resource Report NPS/SFCN/NRR—2008/063. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/660634> (last accessed November 2020).
- Roberts, H. H., L. J. Rouse, N. D. Walker and J. H. Hudson. 1982. Cold-water stress in Florida Bay and northern Bahamas; a product of winter cold-air outbreaks. *Journal of Sedimentary Research* 52(1):145–155.
- Rogers, C. S., E. Muller, T. Spitzack and J. Miller. 2009. Extensive coral mortality in the US Virgin Islands in 2005/2006: A review of the evidence for synergy among thermal stress, coral bleaching and disease. *Caribbean Journal of Science* 45(2–3):204–214.
- Rosenberg, E. and Y. Ben-Haim. 2002. Microbial diseases of corals and global warming. *Environmental Microbiology* 4(6):318–326.
- South Florida/Caribbean Network. 2020a. Testing the precision of HOBO® loggers in a cold bath—Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT01. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278932> (last accessed November 2020).

- South Florida/Caribbean Network. 2020b. Launch HOBO[®] temperature pro v2 logger—Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT02. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278933> (last accessed November 2020).
- South Florida/Caribbean Network. 2020c. Deploying and retrieving HOBO[®] pro v2 temperature loggers —Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT04. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278935> (last accessed November 2020).
- South Florida/Caribbean Network. 2020d. Entering data into the excel field log—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT06. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278937> (last accessed November 2020).
- South Florida/Caribbean Network. 2020e. HOBO[®] temperature pro v2 field data collection using the HOBO[®] waterproof shuttle - U-DTW-1—Version 1.1. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT03. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278934> (last accessed November 2020).
- South Florida/Caribbean Network. 2020f. *.hobo file renaming procedure, conversion and storage—Version 1.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT05. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278936> (last accessed November 2020).
- South Florida/Caribbean Network. 2020g. Importing data to aquarius database—Version 1.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT12. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278941> (last accessed November 2020).
- South Florida/Caribbean Network. 2020h. QA/QC of newly imported HOBO[®] data files into Aquarius—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT08. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278938> (last accessed November 2020).
- South Florida/Caribbean Network. 2020i. Reports, graphing, and web page data—Version 2.0. South Florida/Caribbean Network Standard Operating Procedure NPS/SFCN/SOP—WT09. South Florida/Caribbean Network, Palmetto Bay, Florida. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/2278939> (last accessed November 2020).
- Sowder, C. and E. A. Steel. 2012. A note on the collection and cleaning of water temperature data. Water 4:597–606.

- Whelan, K. R.T., J. Miller., O Sanchez., and M. Patterson. 2007. Impact of the 2005 coral bleaching event on *Porites porites* and *Colpophyllia natans* at Tektite Reef, US Virgin Islands. *Coral Reefs* 26:689–693.
- Winter, A., R. S. Appeldoorn, A. Bruckner, E. H. Williams Jr., and C. Goenaga. 1998. Sea Surface temperatures and coral reef bleaching off La Pargera, Puerto Rico (northeastern Caribbean Sea). *Coral Reefs* 17:377–382.
- Witcher, B. 2007. South Florida/Caribbean Network Data Management Plan. Natural Resource Report NPS/SER/SFCN/NRR—2008/064. National Park Service, Fort Collins, Colorado. Available at: <https://irma.nps.gov/DataStore/Reference/Profile/661961> (last accessed November 2020).

Appendix A. Sample Graphs and Tables from Graphing Templates

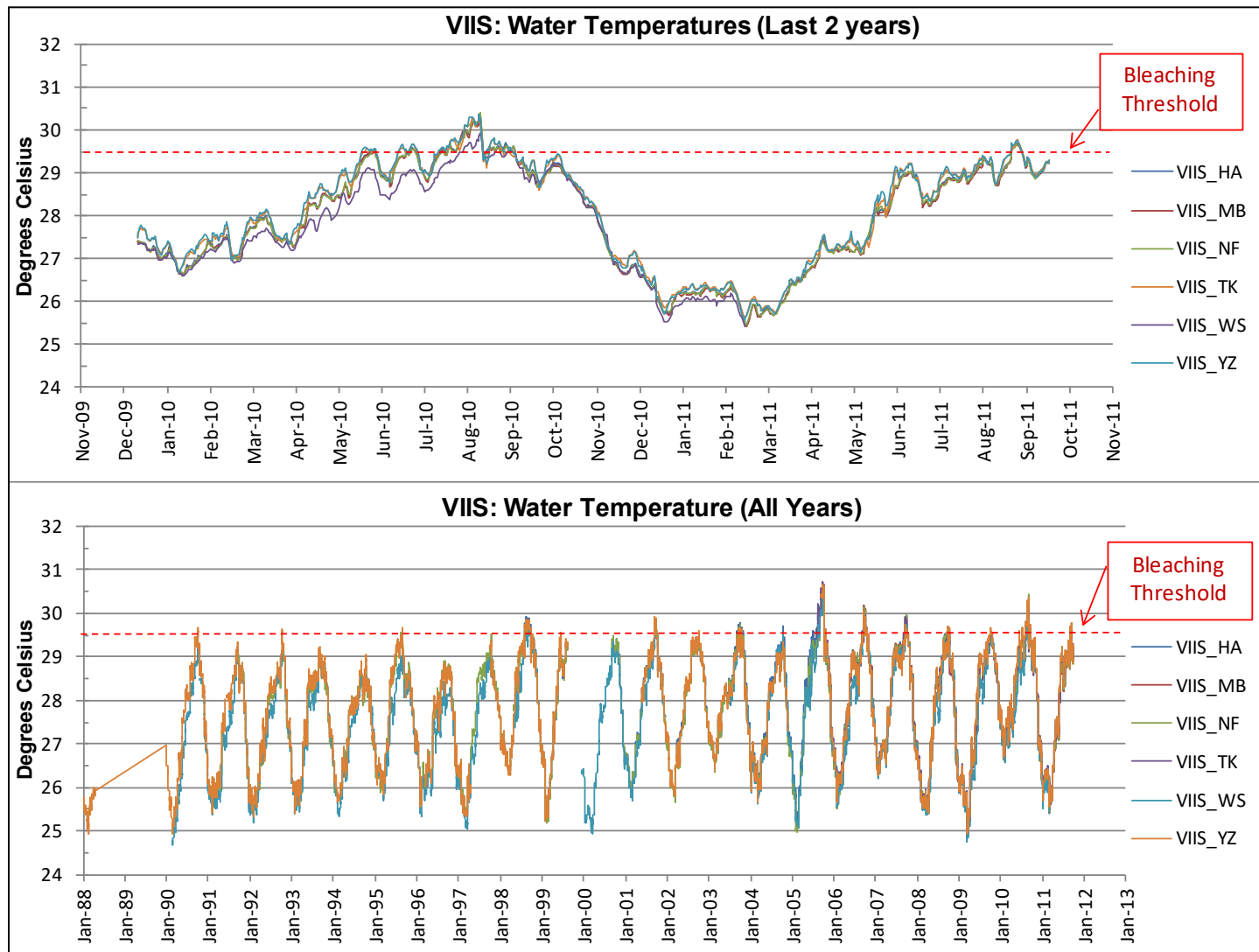


Figure A-1. Virgin Islands National Park water temperature summary graphs. Top: Water temperatures for past two calendar years. Bottom: Graph of all water temperature data. Bleaching stress threshold of 29.5°C (85.1°F) is shown.

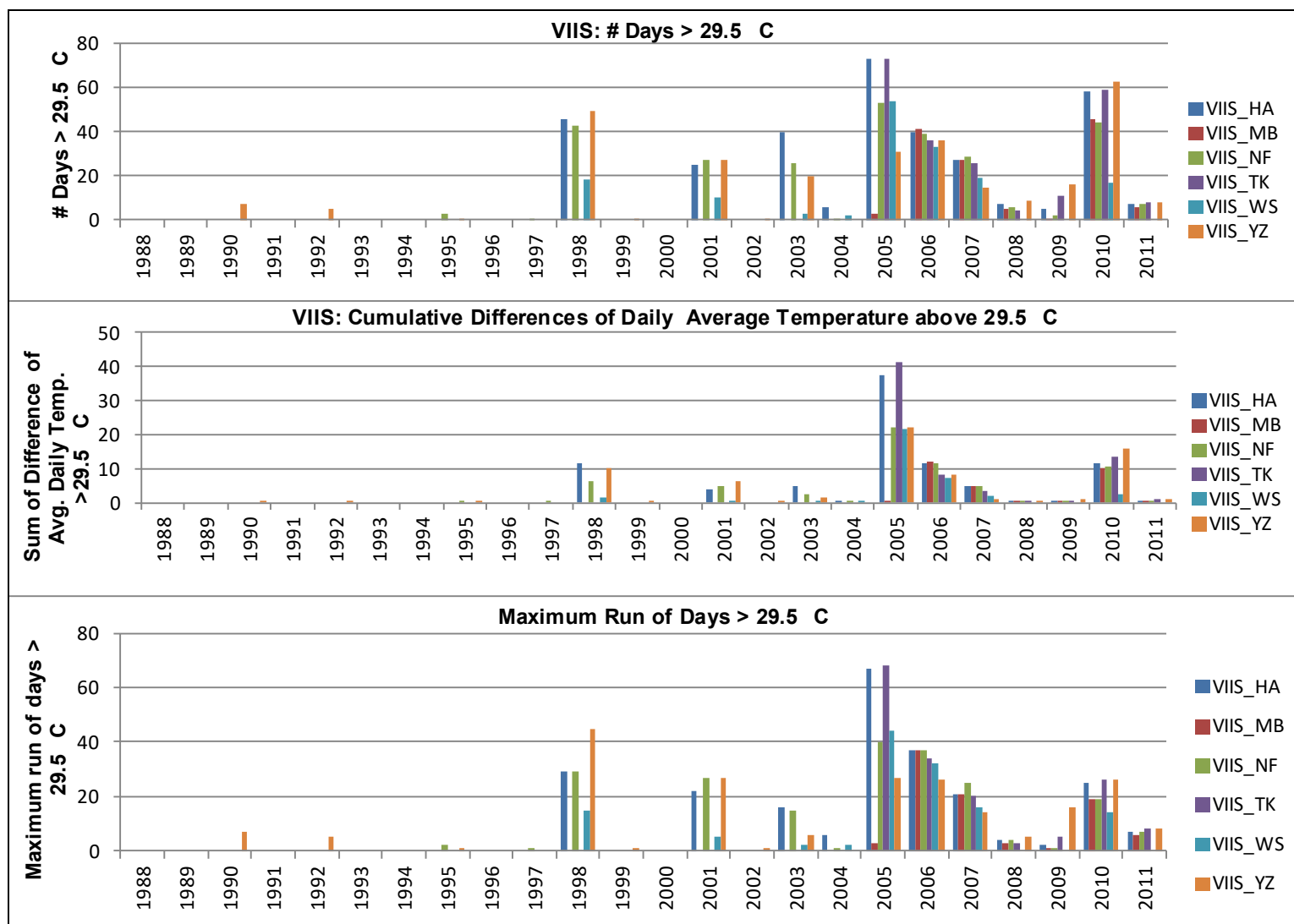


Figure A-2. Virgin Islands National Park water temperature stress threshold graphs. Top: Number of days above 29.5°C (85.1°F) stress threshold. Middle: Cumulative sum of differences of daily average temperature from 29.5°C (85.1°F) for days above the threshold. Bottom: Maximum consecutive run of days above the 29.5°C (85.1°F) threshold.

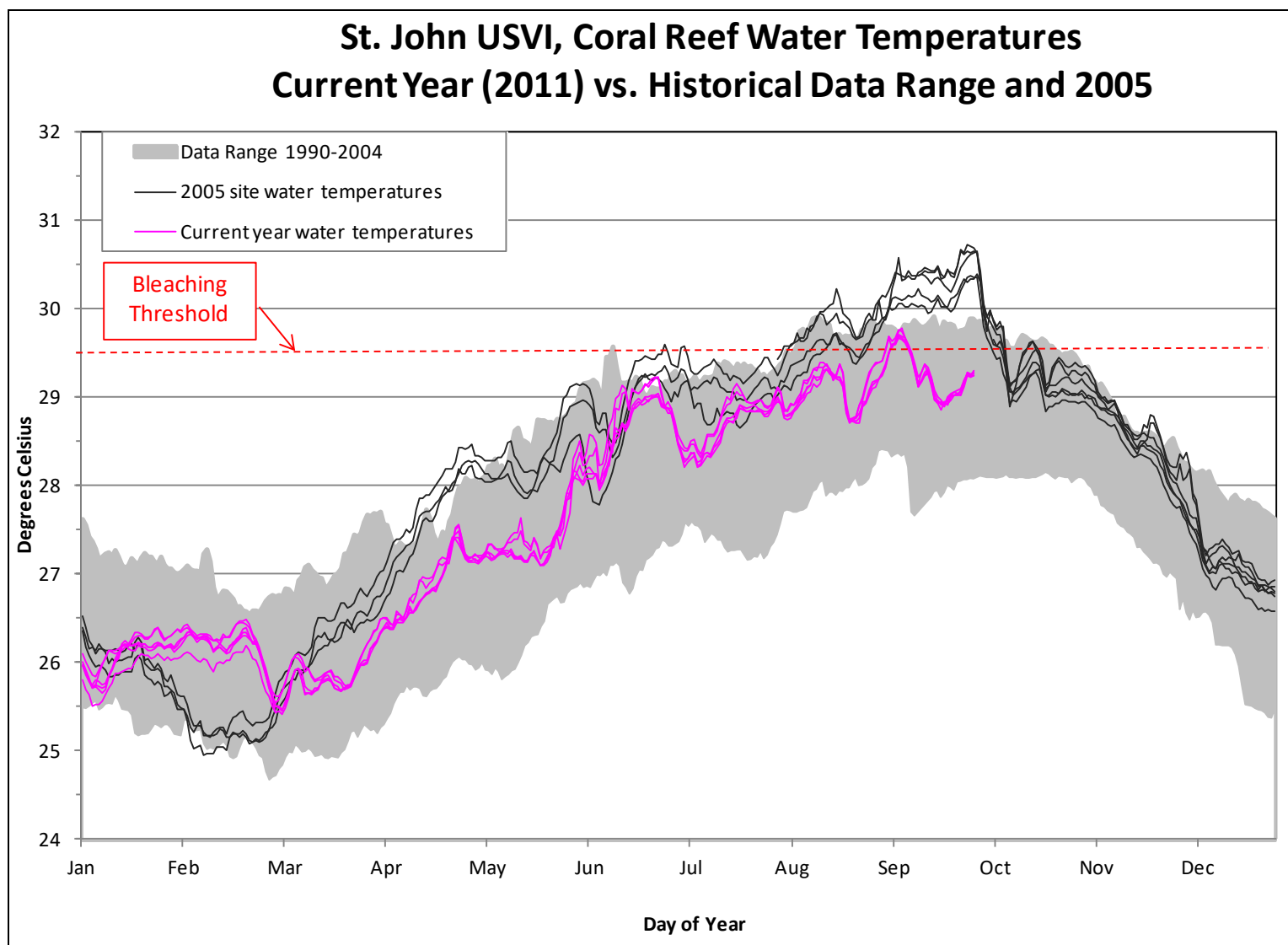


Figure A-3. The current year's water temperature for Virgin Islands National Park compared with 2005 (an extensive bleaching year) and the 1990–2004 range of daily average temperatures for all sites.

Table A-1. Virgin Islands National Park water temperature data summary at coral monitoring sites.

StationName	Year	# Days Monitored	Avg. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	# Days >29.5 °C	Sum of differences >29.5 °C	Maximum Run of Days >29.5 °C	Average of Cold Months (Dec [prev yr] – Mar) (°C)	Average of Warm Months (July–Oct) (°C)
VIIS_HA	1998	148	28.9	29.9	26.8	46	11.5	29	–	29.5
	1999	224	27.4	29.3	25.2	0	0.0	0	26.4	28.9
	2000	100	28.3	29.4	26.5	0	0.0	0	–	29.2
	2001	306	27.9	29.9	25.9	25	4.2	22	26.5	29.1
	2002	280	28.3	29.4	26.5	0	0.0	0	26.8	29.0
	2003	364	28.1	29.8	26.4	40	5.2	16	27.1	29.1
	2004	352	27.7	29.7	25.8	6	0.7	6	26.8	28.9
	2005	365	28.2	30.6	25.2	73	37.4	67	26.2	29.7
	2006	365	28.1	30.2	25.8	40	11.7	37	26.6	29.2
	2007	364	28.1	30.0	26.4	27	5.1	21	27.0	29.3
	2008	366	27.6	29.6	25.5	7	0.3	4	26.3	29.0
	2009	365	27.6	29.5	24.9	5	0.1	2	25.9	29.1
	2010	365	28.3	30.4	26.0	58	11.9	25	27.4	29.4
	2011	273	27.5	29.7	25.5	7	0.8	7	26.2	29.0
VIIS_HA Multi-Year	–	4237	28.0	30.6	24.9	334	89.0	67	26.6	29.2
VIIS_MB	2005	87	28.3	29.6	26.7	3	0.3	3	–	29.2
	2006	365	28.1	30.2	25.7	41	12.1	37	26.5	29.2
	2007	364	28.1	29.9	26.3	27	4.8	21	27.0	29.3
	2008	366	27.6	29.6	25.5	5	0.2	3	26.3	29.0

StationName	Year	# Days Monitored	Avg. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	# Days >29.5 °C	Sum of differences >29.5 °C	Maximum Run of Days >29.5 °C	Average of Cold Months (Dec [prev yr] – Mar) (°C)	Average of Warm Months (July–Oct) (°C)
VIIS_MB (continued)	2009	365	27.6	29.5	24.9	1	0.0	1	25.9	29.1
	2010	365	28.2	30.4	26.0	46	10.2	19	27.4	29.4
	2011	273	27.5	29.7	25.4	6	0.7	6	26.1	28.9
VIIS_MB Multi-Year	–	2185	27.9	30.4	24.9	129	28.3	37	26.5	29.2
VIIS_NF	1991	304	27.2	29.2	25.5	0	0.0	0	25.9	28.7
	1992	366	27.3	29.2	25.3	0	0.0	0	25.9	28.5
	1993	365	27.4	28.9	25.4	0	0.0	0	26.1	28.5
	1994	365	27.3	28.6	25.7	0	0.0	0	26.3	28.2
	1995	365	27.8	29.6	25.7	3	0.1	2	26.5	28.9
	1996	366	27.3	28.9	25.7	0	0.0	0	26.6	28.4
	1997	365	27.6	29.5	25.4	1	0.0	1	26.1	28.8
	1998	361	28.1	29.8	26.3	43	6.6	29	27.1	29.4
	1999	224	27.4	29.3	25.2	0	0.0	0	26.3	28.9
	2000	125	28.5	29.5	26.6	0	0.0	0	–	29.2
	2001	365	27.9	29.8	25.9	27	5.2	27	26.5	29.1
	2002	365	27.8	29.4	25.7	0	0.0	0	26.6	29.0
	2003	365	28.1	29.7	26.4	26	2.6	15	27.1	29.1
	2004	352	27.6	29.5	25.8	1	0.0	1	26.7	28.8
	2005	365	28.0	30.4	25.0	53	22.2	40	26.0	29.5
	2006	365	28.0	30.1	25.5	39	11.9	37	26.3	29.3

StationName	Year	# Days Monitored	Avg. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	# Days >29.5 °C	Sum of differences >29.5 °C	Maximum Run of Days >29.5 °C	Average of Cold Months (Dec [prev yr] – Mar) (°C)	Average of Warm Months (July–Oct) (°C)
VIIS_NF (continued)	2007	363	28.1	30.0	26.4	29	5.2	25	27.0	29.3
	2008	365	27.6	29.6	25.5	6	0.4	4	26.3	29.0
	2009	219	28.6	29.5	26.0	2	0.0	1	26.4	29.1
	2010	365	28.2	30.4	26.0	44	10.5	19	27.4	29.4
	2011	273	27.5	29.7	25.4	7	0.7	7	26.2	29.0
VIIS_NF Multi-Year	–	6968	27.8	30.4	25.0	281	65.3	40	26.5	28.9
VIIS_TK	2005	153	29.2	30.7	26.9	73	41.2	68	–	29.9
	2006	365	28.1	30.1	25.7	36	8.4	34	26.7	29.2
	2007	364	28.1	29.9	26.3	26	3.6	20	27.0	29.2
	2008	365	27.5	29.6	25.4	4	0.2	3	26.3	28.9
	2009	365	27.7	29.6	25.0	11	0.4	5	26.0	29.1
	2010	365	28.4	30.3	26.2	59	13.7	26	27.6	29.4
	2011	273	27.6	29.8	25.6	8	1.2	8	26.3	29.1
VIIS_TK Multi-Year	–	2250	28.0	30.7	25.0	217	68.6	68	26.6	29.2
VIIS_WS	1990	306	27.3	29.3	24.7	0	0.0	0	25.0	28.4
	1991	361	27.0	29.0	25.4	0	0.0	0	26.0	28.3
	1992	366	27.2	29.1	25.2	0	0.0	0	25.8	28.4
	1993	365	27.4	28.9	25.4	0	0.0	0	26.1	28.5
	1994	365	27.2	28.8	25.3	0	0.0	0	26.2	28.2
	1995	365	27.5	29.3	25.7	0	0.0	0	26.6	28.5

StationName	Year	# Days Monitored	Avg. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	# Days >29.5 °C	Sum of differences >29.5 °C	Maximum Run of Days >29.5 °C	Average of Cold Months (Dec [prev yr] – Mar) (°C)	Average of Warm Months (July–Oct) (°C)
VIIS_WS (continued)	1996	366	27.0	28.5	25.3	0	0.0	0	26.4	27.9
	1997	302	27.1	29.0	25.0	0	0.0	0	25.8	28.5
	1998	211	28.8	29.7	27.4	18	1.6	15	–	29.2
	1999	16	26.4	26.4	26.3	0	0.0	0	25.6	28.7
	2000	366	27.3	29.3	24.9	0	0.0	0	26.4	28.9
	2001	347	27.7	29.7	25.7	10	0.8	5	27.8	–
	2003	189	28.5	29.5	26.4	3	0.1	2	–	28.8
	2004	366	27.5	29.5	25.6	2	0.0	2	26.5	28.8
	2005	365	27.9	30.4	25.1	54	21.5	44	26.1	29.4
	2006	351	27.8	30.0	25.6	33	7.3	32	26.4	29.0
	2007	365	28.0	29.8	26.2	19	1.9	16	26.9	29.2
	2008	366	27.4	29.4	25.4	0	0.0	0	26.2	28.8
	2009	365	27.4	29.4	24.8	0	0.0	0	25.9	28.8
	2010	365	28.1	29.9	25.8	17	2.7	14	27.3	29.2
	2011	60	25.9	26.2	25.4	0	0.0	0	26.1	–
VIIS_WS Multi-Year	–	6528	27.5	30.4	24.7	156	35.9	44	26.2	28.7
VIIS_YZ	1988	94	25.5	26.0	24.9	0	0.0	0	25.5	–
	1990	365	27.4	29.7	24.9	7	0.8	7	25.7	28.8
	1991	357	27.3	29.3	25.4	0	0.0	0	26.2	28.6
	1992	366	27.5	29.6	25.4	5	0.4	5	26.0	28.7

StationName	Year	# Days Monitored	Avg. Temp. (°C)	Max. Temp. (°C)	Min. Temp. (°C)	# Days >29.5 °C	Sum of differences >29.5 °C	Maximum Run of Days >29.5 °C	Average of Cold Months (Dec [prev yr] – Mar) (°C)	Average of Warm Months (July–Oct) (°C)
VIIS_YZ (continued)	1993	365	27.6	29.2	25.4	0	0.0	0	26.3	28.7
	1994	365	27.4	29.0	25.7	0	0.0	0	26.4	28.3
	1995	355	27.8	29.7	25.9	1	0.2	1	26.6	29.0
	1996	339	27.4	28.9	25.5	0	0.0	0	26.7	28.4
	1997	190	27.0	29.4	25.3	0	0.0	0	26.0	28.9
	1998	365	28.2	29.9	26.3	49	10.5	45	27.0	29.4
	1999	224	27.5	29.6	25.2	1	0.1	1	26.4	29.0
	2001	222	28.7	29.9	27.0	27	6.4	27	–	29.2
	2002	365	27.9	29.6	25.8	1	0.1	1	26.7	29.1
	2003	365	28.0	29.7	26.4	20	1.6	6	27.2	29.0
	2004	323	27.6	29.3	25.6	0	0.0	0	26.6	28.7
	2005	110	28.8	30.7	26.8	31	22.1	27	–	29.9
	2006	365	28.0	30.1	25.6	36	8.2	26	26.6	29.1
	2007	363	28.0	29.8	26.3	15	1.4	14	26.9	29.1
	2008	364	27.5	29.7	25.4	9	0.8	5	26.2	28.9
	2009	365	27.7	29.7	24.9	16	1.0	16	26.0	29.2
	2010	365	28.4	30.4	26.1	63	16.1	26	27.6	29.5
	2011	273	27.6	29.8	25.5	8	1.3	8	26.3	29.1
VIIS_YZ Multi-Year	–	6865	27.7	30.7	24.9	289	70.7	45	26.5	28.9

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

NPS 910/176514, June 2021

National Park Service
U.S. Department of the Interior



[Natural Resource Stewardship and Science](#)

1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525