Scientists working on the Hawaii Ocean Time-series (HOT) program have been making repeated observations of the hydrography, chemistry and biology of the water column at a station north of Oahu, Hawaii since October 1988. The objective of this research is to provide a comprehensive description of the ocean at a site representative of the North Pacific subtropical gyre. Cruises are made approximately once per month to the deep-water Station ALOHA (A Long-term Oligotrophic Habitat Assessment; 22° 45' N, 158° 00' W) located 100 km north of Oahu, Hawaii. Measurements of the thermohaline structure, water column chemistry, currents, optical properties, primary production, plankton community structure, and rates of particle export are made on each cruise.

A surface mooring, in collaboration with the Woods Hole Oceanographic Institution (WHOI), has also been maintained at Station ALOHA since August 2004. The objective of the WHOI HOT Site (WHOTS) surface mooring is to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water, and chemical fluxes.

This document reports the data collected in 2019. However, we have included some data from 1988-2018 to place the 2019 measurements in the context of ongoing time-series observations. The data reported here are a subset of the complete data set. Summary plots are given for CTD, biogeochemical, optical, shipboard meteorological, navigational, thermostalinograph and ADCP observations, as well as meteorological, temperature, salinity and current observations from the WHOTS mooring. The complete data set resides on a File Server at the University of Hawaii. These data are in ASCII format, and can easily be accessed using either anonymous file transfer protocol (HOT ftp, WHOTS ftp), the World Wide Web (HOT html, WHOTS html) or the Hawaii Ocean Time-series Data Organization and Graphical System (HOT-DOGS).

CTD & bottle data and metadata from each individual CTD cast from HOT cruises are converted to NetCDF (Network Common Data Form) files following OceanSITES (www.oceansites.org) format conventions, and submitted to the OceanSITES data repository. Data files are retrieved from this repository by the NOAA National Centers for Environmental Information (NCEI) and archived in their database. These files are also available in our public ftp site (ftp://ftp.soest.hawaii.edu/hot/netcdf).

HOT data are also available on BCO-DMO (https://www.bco-dmo.org/project/2101). The CTD, bottle, particle flux & primary production data sets can be downloaded via their Website.
ACKNOWLEDGMENTS

Many people participated in the 2019 cruises sponsored by the HOT program. Special thanks are due to Karin Björkman, Tim Burrell, Dan Fitzgerald, Carolina Funkey, Tully Rohrer, Dan Sadler, Ryan Tabata, and Blake Watkins for the tremendous amount of time and effort they have put into the program. Special thanks are given to Jennifer Kondo for her excellent administrative support of the program and Julia Hummon for providing training and advice during the ADCP data processing. Tara Clemente and Eric Grabowski performed many of the core chemical analyses. Karin Björkman, Carolina Funkey, and Ryan Tabata performed the nutrient analyses. Dan Sadler performed the carbon analyses. Daniel Fitzgerald, Tully Rohrer, and Lucie Knor performed the salinity measurements. Kelsey Maloney provided additional technical support. We gratefully acknowledge the support from Sea-Bird for helping us to maintain the quality of the CTD data throughout the HOT program. We also would like to thank the captains and crew of the R/V Kilo Moana, the R/V Oceanus, the NOAA ship Oscar Sette, and the UH Marine Center staff for their efforts. Without the assistance of these and the many technicians, students and ancillary investigators, the data presented in this report could not have been collected, processed, analyzed, and reported. Shipboard ADCP data were collected and processed using Eric Firing’s ADCP data collection/processing suite.

This data set was acquired with funding from the National Science Foundation (NSF) and State of Hawaii general funds. The specific grant which supported our 2019 work is NSF grant OCE-1756517 (White, Karl, and Potemra). Additional support for HOT Research was provided by the Simons Foundation. The WHOTS mooring work was funded in part by the Ocean Observing and Monitoring Division, Climate Program Office (FundRef number 100007298), National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and under grant NA14OAR4320158 to the Woods Hole Oceanographic Institution.
1.0 INTRODUCTION

1.1 Origins

1.1.1 JGOFS & WOCE: 1988 – 2003

In response to the growing awareness of the ocean’s role in climate and global environmental change, and the need for additional and more comprehensive oceanic time-series measurements, the Board on Ocean Science and Policy (BOSP) of the National Research Council (NRC) sponsored a workshop on “Global Observations and Understanding of the General Circulation of the Oceans” in August 1983. The proceedings of this workshop (National Research Council 1984a) served as a prospectus for the development of the U.S. component of the World Ocean Circulation Experiment (WOCE). US-WOCE had the following objectives:

- To understand the general circulation of the global ocean, to model with confidence its present state and predict its evolution in relation to long-term changes in the atmosphere.
- To provide the scientific background for designing an observation system for long-term measurement of the large-scale circulation of the ocean.

In a parallel effort, a separate research program termed Global Ocean Flux Study (GOFS) focused on the ocean’s carbon cycle and associated air-sea fluxes of carbon dioxide. In September 1984, NRC-BOSP sponsored a workshop on “Global Ocean Flux Study” which served as an eventual blueprint for the GOFS program (National Research Council 1984b). In 1986, the International Council of Scientific Unions (ICSU) established the International Geosphere-Biosphere Program: A Study of Global Change (IGBP), and the following year JGOFS (Joint GOFS) was designed as a Core Project of IGBP. US-JGOFS research efforts focused on the oceanic carbon cycle, its sensitivity to change and the regulation of the atmosphere-ocean CO\textsubscript{2} balance (Brewer et al., 1986). The broad objectives of US-JGOFS were:

- To determine and understand on a global scale the time-varying fluxes of carbon and associated biogenic elements in the ocean.
- To evaluate the related exchanges of these elements with the atmosphere, the sea floor and the continental boundaries (Scientific Committee on Oceanic Research 1990).

In order to achieve these goals, four separate program elements were defined: (1) process studies to capture key regular events, (2) long-term time-series observations at strategic sites, (3) a global survey of relevant oceanic properties (e.g., CO\textsubscript{2}), and (4) a vigorous data interpretation and modeling effort to disseminate knowledge and to generate testable hypotheses.

In 1987, two separate proposals were submitted to the US-WOCE and US-JGOFS program committees, respectively, by scientists at the University of Hawaii at Manoa, to establish a multi-disciplinary, deep water hydrostation in proximity to the Hawaiian islands. In July 1988, these proposals were funded by the National Science Foundation and Station ALOHA, the benchmark study site for the Hawaii Ocean Time-series program, was officially on the map (Karl and Lukas 1996). A sister station in the western North Atlantic Ocean, near the historical Panulirus Station, was likewise funded by the US-JGOFS program and is operated by scientists at the Bermuda Biological Station for Research, Inc. (Michaels and Knap 1996).
The primary research objectives of these ocean measurement programs were to establish and maintain deep-water hydrostations for observing and interpreting physical and biogeochemical variability. The program designs called for repeat measurements of a suite of core parameters at approximately monthly intervals, compilation of the data and rapid distribution to the scientific community.

1.1.2 Ocean Carbon & Biogeochemistry (OCB) : 2004 - present

By the end of the JGOFS and WOCE programs in the early 2000s, HOT and BATS found themselves lacking a unified programmatic base that could facilitate community input into science priorities conducted by these programs. The initiation of the OCB program in 2007 provided a scientific support network whose research interests aligned well with these on-going time series efforts. Under the OCB program umbrella, HOT and BATS remain focused on studying processes that control the distributions and cycling of elements in the sea, with specific focus on carbon, in sufficient detail to provide predictive understanding on how global scale perturbations to ocean-climate influence biogeochemical transformations. To achieve this broad objective, the programs seek understanding of the following:

- The linkages between seasonal, interannual, and long-term (multi-decadal) variability and trends in ocean physics, chemistry, and biology.
- Processes underlying physical and biogeochemical temporal variability.
- The role of physical forcing on carbon fluxes, including rates of biologically-mediated carbon transformations, air-sea CO₂ exchange, and carbon export.
- The response of ocean biogeochemistry to ocean change.

Beginning in 2009, under guidance from the National Science Foundation, the two core elements of HOT (biogeochemistry & ecology and physical oceanography) were centralized into a single program. This unification retains the strong interdisciplinary, collaborative structure that has characterized the program since its inception, including a core suite of measurements of biogeochemistry, physics, and ecology. The program remains based at the University of Hawaii where Angelique White and David Karl contributes expertise in biogeochemistry & ecology and satellite remote sensing and James Potemra provides physical oceanographic expertise. In addition, the program retains long-time HOT collaborators: A) John Dore (Montana State University) overseeing inorganic carbon measurements and quality control of core biogeochemical analyses; B) Michael Landry overseeing zooplankton and plankton community structure measurements; and C) Ricardo Letelier overseeing analysis of HPLC pigments. In addition, the program contributes to a NOAA-led, full ocean depth mooring at Station ALOHA (termed the WHOTS mooring), overseen by Robert Weller and Al Plueddemann (Woods Hole Oceanographic Institution).
1.2 Hawaii Ocean Time-series Program

The Hawaii Ocean Time-series (HOT) Program consists of several research components led by scientists at the University of Hawaii at Manoa (Table 1.1). The hydrographic (P.O.) and biogeochemistry & ecology components are fully integrated operationally and are both involved in all aspects of planning and execution of HOT Program objectives.

Table 1.1: HOT Research Components in 2019

<table>
<thead>
<tr>
<th>Scientists</th>
<th>Project role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angelique E. White (lead-PI)</td>
<td>Biogeochemistry and optics</td>
</tr>
<tr>
<td>David M. Karl (co-PI)</td>
<td>Biogeochemistry and ecology</td>
</tr>
<tr>
<td>James T. Potemra (co-PI)</td>
<td>Physical oceanography</td>
</tr>
<tr>
<td>John E. Dore (collaborator)</td>
<td>Inorganic carbon</td>
</tr>
<tr>
<td>Michael Landry (collaborator)</td>
<td>Zooplankton and plankton community structure</td>
</tr>
<tr>
<td>Ricardo M. Letelier (collaborator)</td>
<td>HPLC Pigments</td>
</tr>
<tr>
<td>Robert A. Weller &amp; Albert J. Plueddmann (collaborators)</td>
<td>WHOTS (full ocean depth) mooring</td>
</tr>
</tbody>
</table>

1.3 Scientific objectives for HOT

The primary objective of HOT is to obtain a long time-series of physical and biogeochemical observations in the North Pacific subtropical gyre that will address the goals of the US Global Change Research Program. The program objectives are:

- Document and understand seasonal and interannual variability of water masses.
- Relate water mass variations to gyre fluctuations.
- Develop a climatology of short-term physical variability.
- Document and understand seasonal and interannual variability in the rates of primary production, new production and particle export from the surface ocean.
- Determine the mechanisms and rates of nutrient input and recycling, especially for nitrogen (N) and phosphorus (P) in the upper 200 m of the water column.
- Measure the time-varying concentrations of dissolved inorganic carbon (DIC) in the upper water column and estimate the annual air-to-sea CO₂ flux.

In addition to these primary objectives, the HOT Program provides logistical support for numerous complementary research programs (Table 1.2). A complete listing of these projects can be obtained from the HOT web page (hahana.soest.hawaii.edu/hot/ancillary.html).
Table 1.2: Ancillary Projects Supported by HOT in 2019

<table>
<thead>
<tr>
<th>Principal Investigator(s)</th>
<th>Institution</th>
<th>Agency</th>
<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matthew Church</td>
<td>UM/FLBS</td>
<td>SF</td>
<td>Diversity and activities of nitrogen-fixing microorganisms</td>
</tr>
<tr>
<td>Andrew Dickson</td>
<td>UCSD SIO</td>
<td>NSF</td>
<td>$^{13}C/^{12}C$ ratio of atmosphere carbon dioxide and oceanic carbon in relation to the global carbon cycle</td>
</tr>
<tr>
<td>Karl, Armbrust &amp; others</td>
<td>Various</td>
<td>SF</td>
<td>Simons Collaboration on Ocean Processes and Ecology</td>
</tr>
<tr>
<td>David Karl &amp; Sara Ferrón-Smith</td>
<td>UH</td>
<td>NSF</td>
<td>Determination of gross primary production from the euphotic zone</td>
</tr>
<tr>
<td>David Karl &amp; Sam Wilson</td>
<td>UH</td>
<td>NSF</td>
<td>Reduced gases in the upper ocean: The cycling of methane, sulfide and nitrous oxide</td>
</tr>
<tr>
<td>Matthew McCarthy &amp; Tom Guilderson</td>
<td>UCSC</td>
<td>NSF</td>
<td>Sediment trap samples to look at amino acid-based paleo proxies</td>
</tr>
<tr>
<td>Paul Quay</td>
<td>UW</td>
<td>NOAA</td>
<td>$^{13}C/^{12}C$ of dissolved inorganic carbon in the ocean</td>
</tr>
</tbody>
</table>

1.4 HOT Study Site

There are both scientific and logistical considerations involved with the establishment of any long-term, time-series program. Foremost among these are site selection, choice of variables and general sampling design and sampling frequency. Equally important are choices of analytical methods for a given candidate variable, an assessment of the desired accuracy and precision of each measurement, availability of suitable reference materials, the hierarchy of sampling replication and mesoscale horizontal variability.

We evaluated several major criteria prior to selection of the site for the HOT oligotrophic ocean benchmark hydrostation. First, the station must be located in deep water (>4000 m), upwind (north-northeast) of the main Hawaiian Islands and of sufficient distance from land to be free from coastal ocean dynamics and biogeochemical influences. On the other hand, the station should be close enough to the port of Honolulu to make relatively short duration (<5 d) monthly cruises logistically and financially feasible. A desirable, but less stringent criterion would locate the station at, or near, previously studied regions of the central North Pacific Ocean, in particular Station GOLLUM (22° 10’N, 158° 00’W). Documentation of oceanic time-series measurements in the North Pacific Ocean can be found in Karl and Winn (1991), Karl et al. (1996b), Karl and Lukas (1996) and in the HOT web page (hahana.soest.hawaii.edu/hot).
After consideration of these criteria, we established our primary sampling site at 22° 45' N, 158° W at a location approximately 100 km north of the island of Oahu (Figure 1.1), and generally restrict our monthly sampling activities to a circle with a 6 nautical mile radius around this nominal site (Figure 1.2). Station ALOHA is in deep water (4750 m) and is more than one Rossby radius (50 km) away from steep topography associated with the Hawaiian Ridge. We also established a coastal station WSW of the island of Oahu approximately 10 km off Kahe Point (21° 20.6' N, 158° 16.4' W) in 1500 m of water, as well as a mid-water station Kaena (21° 50.8' N, 158° 21.8' W) WNW of Oahu in 2500m of water.

Station Kahe serves as a coastal analogue to our deep-water site and the data collected there provide a near-shore time-series for comparison to our primary open ocean site. Station Kahe is also used to test our equipment each month before departing for Station ALOHA, and to orient new personnel at the beginning of each cruise.

The sub-sea ridge between Oahu and Kauai (where the Station Kaena is located) is an area of high internal tide energy (http://www.soest.hawaii.edu/PubServices/1999pdfs/Luther.pdf). It was the focus of the Hawaii Ocean Mixing Experiment (HOME) and the data from HOT cruises at this site have been used for diapycnal mixing studies (Finnigan et al., 2002)
From January 1997 to October 2000, a physical-biogeochemical mooring was deployed to obtain continuous measurements of various atmospheric and oceanographic parameters. The mooring was located at 22° 28’ N, 158° 8’ W and was designated as Station HALE-ALOHA. From August 2004 to July 2007, HALE-ALOHA was redeployed at a site 6 nautical miles west of Station ALOHA (22° 46’ N, 158° 5.5’ W) as part of the Multi-disciplinary Ocean Sensors for Environmental Analyses and Networks (MOSEAN) project. MOSEAN was directed toward new technologies that would lead to increased observations that are essential for solving a variety of interdisciplinary oceanographic problems. These include: biogeochemical cycling, climate change effects, ocean pollution, harmful algal blooms (HABs), ocean ecology and underwater visibility. This site, also called Station 51, was a collaboration with the University of California Santa Barbara and WET Labs.

Also in August 2004, a surface mooring outfitted for meteorological and oceanographic measurements was deployed 6 nautical miles east of Station ALOHA (22° 46’ N, 157° 54’ W). This site, named WHOTS (Woods Hole Oceanographic Institution [WHOI] Hawaii Ocean Time-series [HOT] Site) is a collaboration with the Woods Hole Oceanographic Institution. It has also been called Station 50. The mooring has been turned around once a year since 2004, alternating its location between Station 50 and Station 52, 6 nautical miles south of Station ALOHA (22° 40’N, 157° 57’W). It is intended to provide long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, fresh water, and chemical fluxes (http://www.soest.hawaii.edu/whots).

Locations and dates of occupancy of HOT water column and bottom recording stations are available on the HOT web page (hahana.soest.hawaii.edu/hot/locations.html).
Figure 1.2: [Left panels] Drift tracks of the sediment trap array during each HOT cruise in 2019. Starting point of deployment indicated by “S”. [Right panels] CTD cast locations during each HOT cruise in 2019. Location numbers correspond to cast numbers. Dashed line indicates the 10 km radius circle defining the station.
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: Due to rough seas and predicted high winds on the recovery day during HOT-317, the sediment trap array was not deployed.
1.5 Field Sampling Strategy

HOT program cruises are conducted at approximately monthly intervals; the exact timing is dictated by the availability of research vessels. From HOT-1 (October 1988) to HOT-65 (August 1995), with the exception of HOT-42 and HOT-43 (November and December 1992), each cruise was 5 d in duration (port to port). Beginning with HOT-66 (September 1995) the standard HOT cruise was reduced to 4 d in order to accommodate the additional mooring-based HOT field programs within a fixed per annum allocation of ship days.

From HOT-1 (October 1988) to HOT-32 (December 1991), underway expendable bathythermograph (XBT; Sippican T-7 probes) surveys were conducted at 13 km spacing on the outbound transect from Station Kahe to Station ALOHA. These surveys were later discontinued because the space-time correlation of the energetic, internal semi-diurnal tides made it difficult to interpret these data. From February 1995 until December 1997 we added an instrumented, 1.5 m Endeco towfish package (Sea-Bird CTD, optical plankton counter and fluorometer) to our sampling program (Tupas et al., 1997). Upper water column currents are measured both underway and on station using a hull-mounted Acoustic Doppler Current Profiler (ADCP), when available (Firing, 1996).

Underway near-surface measurement of a variety of physical, chemical, and biological properties were made possible by sampling seawater through a pumped intake system positioned in the hull of the R/V Moana Wave. In May 1995, a thermosalinograph was installed in line to the ship's seawater intake system. In July 1996, the existing system was replaced with a non-contaminating PVC/stainless steel system. A flow-through fluorometer was installed in 1996. The R/V Ka'imikai-O-Kanaloa was outfitted with a similar seawater intake system to which the existing instruments were installed when R/V Moana Wave was retired. The R/V Kilo Moana also has a similar system which was sampled from during 2019.

The majority of our sampling effort, approximately 60-72 h per standard HOT cruise, is spent at Station ALOHA. High vertical resolution environmental data are collected with a Sea-Bird CTD having external temperature (T), conductivity (C), dissolved oxygen (DO), and fluorescence (F) sensors and an internal pressure (P) sensor. A Sea-Bird 24-place carousel and an aluminum rosette that is capable of supporting 24 12-L PVC bottles are used to obtain water samples from desired depths. The CTD and rosette are deployed on a 3-conductor cable allowing for real-time display of data and for tripping the bottles at specific depths of interest. The CTD system takes 24 samples s⁻¹ and the raw data are stored both on the computer and, for redundancy, on VHS-format video tapes.

In February 2006, before cruise 178, we replaced our 24 aging 12-L PVC rosette bottles with new 12-L bottles fabricated at the University of Hawaii Engineering Support Facility, using plans and specifications from John Bullister (PMEL).

Up until HOT-96 (August 1998), we routinely conducted a dedicated hydrocast to collect “clean” water samples for biological rate measurements, using General Oceanics Go-Flo bottles, Kevlar line, a metal-free sheave, Teflon messengers, and a stainless steel bottom weight. During HOT-97 through HOT-118, due to the frequency of mis-trips & the inability to know the exact depth from which samples were collected, replicate samples were taken from the CTD rosette
and the Go-Flo bottles. Comparisons with the Go-Flo collected samples showed there was no statistical difference in rates of $^{14}$C-primary production derived from samples collected using the Go-Flo bottles or the CTD rosette. As a result, beginning with HOT-119 (October 2000), we have collected samples for biological rate measurements only from the rosette.

A free-drifting sediment trap array, identical in design to the VERTEX particle interceptor trap (PIT) array (Knauer et al., 1979), is deployed at Station ALOHA for an approximately 60 h period to collect sinking particles for chemical and microbiological analyses.

Sampling at Station ALOHA typically begins with sediment trap deployment followed by a deep (> 4700 m) CTD cast and a “burst series” of at least 13 consecutive 1000 m casts, on 3-h intervals, to span the local inertial period (~ 31 h) and three semidiurnal tidal cycles. The drift tracks of the sediment trap arrays and the location of the CTD casts for each cruise are shown in Figure 1.2. The repeated CTD casts enable us to calculate an average density profile from which variability on tidal and near-inertial time scales has been removed. These average density profiles are useful for the comparison of dynamic height and for the comparison of the depth distribution of chemical parameters from different casts and at monthly intervals. This sampling strategy is designed to assess variability on time scales of a few hours to a few years. Very high frequency variability (< 6 h) and variability on time scales of between 3-60 d are not adequately sampled with our ship-based operations.

Water samples for a variety of chemical and biological measurements are routinely collected from the surface to within 10 m of the seafloor. To the extent possible, we collect samples for complementary biogeochemical measurements from the same or from contiguous casts to minimize aliasing caused by time-dependent changes in the density field. This approach is especially important for samples collected in the upper 350 m of the water column. Furthermore, we attempt to sample from common depths and specific density horizons each month to facilitate comparisons between cruises. Water samples for salinity determinations are collected from every water bottle to identify sampling errors. Approximately 20% of the water samples are collected and analyzed in duplicate or triplicate to assess and track our precision in sample analyses.

The HOT program relies on a selected set of core suite environmental variables that are expected to display detectable change on time scales of several days to one decade. Except for the availability of existing satellite and ocean buoy sea surface data, the initial phase of the HOT program (Oct 1988 - Feb 1991) was entirely supported by research vessels. In February 1991, an array of five inverted echo sounders (IES) was deployed in an approximately 150 km$^2$ network around Station ALOHA (Chiswell 1996) and in June 1992, a sequencing sediment trap mooring was deployed a few km north of Station ALOHA (Karl et al., 1996a). In 1993, the IES network was replaced with two strategically-positioned instruments: one at Station ALOHA and the other at Station Kaena. The IES at Station Kaena was retired in October 1995. Between 1994 and 1999, a single IES was positioned and annually replaced at Station ALOHA.
1.6 WHOTS Mooring

In 2003, Robert Weller (Woods Hole Oceanographic Institution [WHOI]), Albert Plueddemann (WHOI), and Roger Lukas (University of Hawaii [UH]) proposed to establish a long-term surface mooring at Station ALOHA to monitor sustained, high-quality air-sea fluxes and the associated upper ocean response as a coordinated part of the HOT program, and as an element of the array of global ocean reference stations supported by the National Oceanic and Atmospheric Administration’s (NOAA) Office of Climate Observation.

With support from the NOAA and the National Science Foundation (NSF), the WHOI HOT Site (WHOTS) surface mooring has been maintained at Station ALOHA since August 2004. This project aims to record long-term, high-quality air-sea fluxes as a coordinated part of the HOT program and contribute to the goals of observing heat, freshwater, and chemical fluxes at a site representative of the oligotrophic North Pacific Ocean. The approach is to maintain a surface mooring outfitted for meteorological and oceanographic measurements at a site near Station ALOHA by successive mooring turnarounds. These observations will be used to investigate air-sea interaction processes related to climate variability.

The mooring system is described in the mooring deployment and recovery cruise reports (Plueddemann et al., 2006; Whelan et al., 2007, 2008, 2010; Santiago-Mandujano et al., 2009, 2018; Hasbrouck et al., 2019, Santiago-Mandujano, et al., 2018, 2021). Briefly, a Surlyn foam surface buoy is equipped with meteorological instrumentation including two complete Air-Sea Interaction Meteorological (ASIMET) systems, measuring air and sea surface temperatures, relative humidity, barometric pressure, wind speed and direction, incoming shortwave and longwave radiation, and precipitation (Colbo and Weller, 2009). Complete surface meteorological measurements are recorded every minute, as required to compute air-sea fluxes of heat, freshwater, and momentum. Each ASIMET system also transmits hourly averages of the surface meteorological variables via the Argos satellite system. The mooring line is instrumented to collect time series of upper ocean temperatures, velocities, and salinities coincident with the surface forcing record. This includes vector measuring current meters, conductivity, salinity and temperature recorders, and Acoustic Doppler Current Profiler (ADCP) instrumentation.

The subsurface instrumentation is located to resolve the temporal variations of shear and stratification in the upper pycnocline to support the study of mixed layer entrainment. Experience with moored profiler measurements near Hawaii suggests that Richardson number estimates over 10 m scales are adequate. Salinity is essential to the stratification, as salt-stratified barrier layers are observed at HOT and in the region. Hence, we use Sea-Bird SeaCATs and MicroCATs with vertical separation ranging from 5 to 20 m to measure temperature and salinity. We use two ADCPs made by Teledyne RD Instruments to obtain current profiles across the entrainment zone and in the mixed layer zone. Both ADCPs are in an upward-looking configuration, one is at 125 m, using 4 m bins, and the other is at 47.5 m using 2 m bins. To provide near-surface velocity (where ADCP estimates are less reliable), we deploy two Vector Measuring Current Meters (VMCMs). The nominal mooring design is a balance between resolving extremes versus the typical annual cycling of the mixed layer. A pair of Sea-Bird SeaCATs (SBE-16) or MicroCATs (SBE-37) have been included since the WHOTS-9 deployment (June 2012) to measure near-bottom temperature and salinity.
1.7 Core Measurements, Experiments and Protocols

The suite of core measurements provides a database to validate and improve existing biogeochemical models. Our list of core measurements has evolved since the inception of the HOT program in 1988, and now includes both continuous and discrete physical, biological and chemical ship-based measurements, optical, *in situ* biological rate experiments, and observations and sample collections from bottom-moored instruments and buoys (Table 1.3). Continuity in the measurement parameters and their quality, rather than continuity in the methods employed, is of greatest interest. Detailed analytical methods are expected to change over time through technical improvements. In addition to the core data, specialized measurements and process-oriented experiments have also been conducted at Station ALOHA (Table 1.3).

Table 1.3: Parameters Measured at Station ALOHA during 2019

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Depth Range (m)</th>
<th>Analytical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Continuous Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth (Pressure)</td>
<td>0-4750</td>
<td>Pressure transducer on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Temperature</td>
<td>0-4750</td>
<td>Thermistor on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Conductivity (Salinity)</td>
<td>0-4750</td>
<td>Conductivity sensor on Sea-Bird CTD package, with discrete salinity samples calibration</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>0-4750</td>
<td>Sea-Bird sensor on Sea-Bird CTD package, with discrete oxygen samples calibration</td>
</tr>
<tr>
<td>Fluorescence (Chloropigment)</td>
<td>0-4750</td>
<td>Sea-Point chlorophyll fluorometer on Sea-Bird CTD package with discrete chlorophyll calibration</td>
</tr>
<tr>
<td><strong>II. Water Column Chemical Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>0-4750</td>
<td>Guildline AutoSal using Wormley seawater standard</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0-4750</td>
<td>Winkler titration</td>
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<tr>
<td>Dissolved Inorganic Carbon</td>
<td>0-4750</td>
<td>Coulometry</td>
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<td>Total Alkalinity</td>
<td>0-4750</td>
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<td>pH</td>
<td>0-4750</td>
<td>Spectrophotometric</td>
</tr>
<tr>
<td>Nitrate Plus Nitrite</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
</tr>
<tr>
<td>Soluble Reactive Phosphorus (SRP)</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
</tr>
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<td>Silicate</td>
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<td>Particulate Carbon</td>
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<tr>
<td>Particulate Nitrogen</td>
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### Particulate Phosphorus
0-350 High temperature combustion

### Particulate Silica
0-175 Base Hydrolysis

#### III. Biomass Measurements

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<td>Chlorophyll a and Pheopigments</td>
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<td>Fluorometric analysis using 10-AU</td>
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<tr>
<td>Pigments</td>
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<td>High Performance Liquid Chromatography (HPLC)</td>
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<td>Adenosine 5’-triphosphate</td>
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<td>Bacteria and Cyanobacteria</td>
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#### IV. Carbon Assimilation and Particle Flux

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<td>$^{14}$C-bicarbonate <em>in situ</em> incubations</td>
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<td>Carbon, Nitrogen, Phosphorus, Silica</td>
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<td>Free-floating particle interceptor traps</td>
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#### V. Currents

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<td>Hull mounted, RDI #OS-38</td>
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<tr>
<td>Acoustic Doppler Current Profiler</td>
<td>10-100</td>
<td>Hull mounted, RDI #WH-300</td>
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#### VI. Optical Measurements

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<td>Incident Irradiance</td>
<td>Surface</td>
<td>LI-COR LI-1500 &amp; Satlantic HyperOCR Hyperspectral Radiometer</td>
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<td>Upwelling Radiance and Downwelling Irradiance</td>
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<td>Satlantic Profiler II with HyperOCR Hyperspectral Radiometers &amp; WET Labs ECO-BB2F Triplet</td>
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<td>Particle Size Analysis</td>
<td>0-200</td>
<td>Sequoia Laser In-Situ Scattering &amp; Transmissometry (LISST-100X)</td>
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#### VII. Bow Intake System

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<td>Temperature</td>
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<td>Conductivity (Salinity)</td>
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<td>Sea-Bird temperature and conductivity sensors inside the thermosalinograph package, with discrete salinity samples calibration</td>
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<td>Fluorometry (Chloropigment)</td>
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#### VIII. Moored Instruments

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These selected measurements are part of a much larger HOT program data set on physical and biogeochemical variability at Station ALOHA that has been collected since October 1988. The complete data set is available to the community by several methods that are described in Section 8.0 of this report.

This report presents selected core data collected during the 31st full year of the HOT Program (January-December 2019). During this period, eight HOT cruises were conducted using the University of Hawaii research vessel Kilo Moana and one on the Oregon State University research vessel Oceanus (Table 1.4). In addition, selected data collected with the WHOTS-15 mooring instruments (September 2018 through October 2019), and during the mooring recovery cruise (WHOTS-16) on board the NOAA ship Oscar Sette are presented here (see Pacheco et al. 2020).

University of Hawaii shipboard technical assistance personnel assisted a total field scientific crew of 72 HOT staff, students and visiting scientists (Table 1.5) in our 2019 field work.

Table 1.4: Chronology of 2019 HOT Cruises

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<td>R/V Oscar Sette</td>
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<td>R/V Oceanus</td>
<td>16 October 2019</td>
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Table 1.5: 2019 Cruise Personnel (shaded area = cruise participant)

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2.0 SAMPLING PROCEDURES AND ANALYTICAL METHODS

A comprehensive summary of all sampling and analytical methods currently used in the HOT program along with information on measurement accuracy and precision can be found in the "Hawaii Ocean Time-series Program Field and Laboratory Protocols" manual. Brief summaries of methods as well as calibration specifications and quality control / quality assurance information for 2019 are presented in this report. Hydrographic sampling methods are included in "WOCE Hydrographic Sampling Procedure. A primer for ship-board operations at the Hawaii Ocean Time-series Station".

2.1 CTD Profiling

Continuous measurements of temperature, salinity, oxygen, and fluorescence are made with a Sea-Bird SBE-9/11Plus CTD package with dual temperature, salinity, oxygen sensors, and fluorometer described in Tupas et al. (1995). In 2019, the CTD underwater unit #91361 was used during cruises HOT-309 through HOT-317. In addition, an ISUS nitrate sensor (SN 97) had been installed in one of the CTD channels since cruise HOT-253, but it was no longer used after HOT-304.

CTD casts were made at Stations Kahe and ALOHA during each cruise in 2019. At Station ALOHA, a burst of consecutive CTD casts to 1000 m was made over 36 hours to span the local inertial period and three semi-diurnal tidal cycles. The full 36-hour burst sampling period was completed during all HOT cruises in 2019, except for HOT-310 and -317, when operations were canceled early due to rough weather. Two near-bottom CTD casts within about 10 m of the bottom were made during each 2019 cruise, except for HOT-317 which only had one near-bottom cast.

CTD casts to depths ranging between 2400 and 2500 m were conducted at Station Kaena during HOT-311, -312, -313, -315, and -316.

CTD casts have been conducted during cruises near the WHOTS mooring since August 2004 to calibrate the moorings’ sensors. Five yo-yo cycles to 200 m depth were performed near the WHOTS-15 mooring (Station 50: 22° 46.045'N, 157° 53.888' W) near the eastern edge of the ALOHA circle during 2019 for cruises HOT-309 through -315, except for HOT-314, which consisted of four cycles conducted to 200 dbar and one cycle to 1020 dbar. After cruise HOT-315, the WHOTS-15 mooring was recovered during the WHOTS-16 cruise, and the WHOTS-16 mooring was deployed near the southeastern edge of the ALOHA circle (Station 52: 40° 0.10'N, 157° 56.961' W). Station 52 was occupied during HOT-316. Five yo-yo cycles were conducted to 200 dbar during this cruise. CTD yo-yo casts were also conducted near the mooring during the WHOTS-16 cruise before recovering the WHOTS-15 mooring and after WHOTS-16 mooring’s deployment (Section 2.10).

2.1.1 Data Acquisition and Processing

CTD data were acquired at a rate of 24 samples per second. Digital data were stored on a laptop personal computer, and for redundancy, the CTD signal was recorded on VHS videotapes.
Backups of CTD data were made onto USB storage cards and later onto compact disks. The raw CTD data were quality controlled and screened for spikes described in Winn et al. (1993). Data alignment, averaging, correction, and reporting were done as described in Tupas et al. (1993). Salinity spike rejection parameters were modified for some cruises in 2019 because of rough sea conditions. Spikes occur when the CTD samples the disturbed water of its wake; therefore, samples from the downcast are rejected when the CTD moves upward or when its acceleration exceeds 0.5 m s\(^{-2}\) in magnitude.

Some cruises were conducted under rough to very rough conditions. The CTD acceleration cutoff value had to be increased to between 0.55 and 0.70 m s\(^{-2}\) for some casts to relax the data rejection criteria and avoid eliminating excessive points. The World Meteorological Organization (WMO) Sea State codes are as follows:

<table>
<thead>
<tr>
<th>WMO Code</th>
<th>Wave height</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 metres (0 ft)</td>
<td>Calm (glassy)</td>
</tr>
<tr>
<td>1</td>
<td>0 to 0.1 metres (0.00 to 0.33 ft)</td>
<td>Calm (rippled)</td>
</tr>
<tr>
<td>2</td>
<td>0.1 to 0.5 metres (3.9 in to 1 ft 7.7 in)</td>
<td>Smooth (wavelets)</td>
</tr>
<tr>
<td>3</td>
<td>0.5 to 1.25 metres (1 ft 8 in to 4 ft 1 in)</td>
<td>Slight</td>
</tr>
<tr>
<td>4</td>
<td>1.25 to 2.5 metres (4 ft 1 in to 8 ft 2 in)</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>2.5 to 4 metres (8 ft 2 in to 13 ft 1 in)</td>
<td>Rough</td>
</tr>
<tr>
<td>6</td>
<td>4 to 6 metres (13 to 20 ft)</td>
<td>Very rough</td>
</tr>
<tr>
<td>7</td>
<td>6 to 9 metres (20 to 30 ft)</td>
<td>High</td>
</tr>
</tbody>
</table>

The data were additionally screened by comparing the temperature and conductivity sensor pairs. These differences permitted the identification of problems in the sensors. Only the data from one set of T-C sensors and one oxygen sensor, whichever was deemed most reliable, are reported here.

Temperature is reported on the ITS-90 scale. Salinity and all derived units were calculated using the UNESCO (1981) routines; salinity is reported in the practical salinity scale (PSS-78). Oxygen is reported in μmol kg\(^{-1}\). Chloropigment (Fluorescence) is reported in μg/l.

### 2.1.2 Sensor Corrections and Calibrations

#### 2.1.2.1 Pressure

The pressure calibration strategy employed a high-quality quartz pressure transducer as a transfer standard. Periodic recalibrations of this laboratory standard were performed with a primary pressure standard. The transfer standard was used to check the CTD pressure transducers. The corrections applied to the CTD pressures included a constant offset determined when the CTD first enters the water on each cast, and a pressure-dependent offset, obtained from semi-annual bench tests between the CTD sensor and the transfer standard.

#### 2.1.2.1.1 Transfer Standard Calibration

The transfer standard is a Digiquartz portable standard Paroscientific SN 136923 pressure gauge equipped with a 10,000-PSI transducer. This instrument was purchased in May 2016 and
was originally calibrated against a primary standard. Subsequent recalibration was performed in May 2020 at Fluke. Calibrations before 2016 were conducted with a Paroscientific Model 760 pressure gauge which was in service between 1988 and 2014 (Fujieki et al., 2020).

2.1.2.1.2 CTD Pressure Transducer Bench Tests

CTD pressure transducer bench tests were done using an Ametek T-100 pump and a manifold to apply pressure simultaneously to the CTD pressure transducer and the transfer standard. All these tests had points at six pressure levels between 0 and 4500 dbar, increasing and decreasing pressures. The results of bench tests for sensors #75434 (CTD #91361) are shown in Table 2.1. This pressure sensor failed and displayed bad data during one of the bench tests, and the sensor’s card was replaced at Sea-Bird in April 2016, modifying the sensor’s characteristic slope and offset. Therefore, only bench tests after this date are included in Table 2.1.

A correction of 0.861 dbar was applied to the pressure offset at 0 dbar during data collection for casts conducted with sensor #75434. However, a more accurate offset was later determined when the CTD first enters the water on each cast. On-deck CTD pressures are regularly recorded during cruises at the beginning, and the end of each CTD cast, the mean of these pressures throughout each cruise is plotted in Figure 2.1 (0.861 dbar offset correction applied to casts has been removed in this plot to make it comparable with the data in Table 2.1).

Figure 2.1: Median value of on-deck pressure measured with the CTD pressure sensors #75434 before (circles) and after (crosses) each cast for HOT cruises 309 through 317. Error bars are one standard deviation from the mean. Cruise numbers are shown in the upper X-axis.
Table 2.1 indicates that the 0-dbar pressure for sensor #75434 was near constant during 2019 and decreased slightly between January 2019 and the August 2019 calibration. These pressures are smaller than the maximum difference between before-cast and after-cast on-deck pressure (Figure 2.1) because during bench tests the CTD is powered on at least 12 hours before testing to allow the pressure sensor to stabilize, while during cruises the CTD is powered on only about 15 minutes before each cast. The bench tests show that a slow sensor stabilization accounts for the observed differences.

The 0-4500 dbar pressure offset and hysteresis from the bench tests have been near-constant and within expected values. A linear pressure-dependent offset was applied during data collection for sensor #75434 to correct the 0-4500 dbar span offset of about 0.27 dbar from the September 2017 bench test (Table 2.1).

Table 2.1: CTD Pressure Calibrations against transfer standard. Units are in decibars.

<table>
<thead>
<tr>
<th>Calibration Date</th>
<th>Offset @ 0 dbar</th>
<th>0-4500 dbar offset</th>
<th>Hysteresis</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-Aug-19</td>
<td>0.75</td>
<td>0.18</td>
<td>0.05</td>
</tr>
<tr>
<td>24-Jan-19</td>
<td>1.14</td>
<td>0.35</td>
<td>0.09</td>
</tr>
<tr>
<td>17-Jul-18</td>
<td>1.04</td>
<td>0.21</td>
<td>0.09</td>
</tr>
<tr>
<td>7-Feb-18</td>
<td>1.06</td>
<td>0.14</td>
<td>0.03</td>
</tr>
<tr>
<td>7-Sep-17</td>
<td>1.05</td>
<td>0.27</td>
<td>0.10</td>
</tr>
<tr>
<td>18-Jan-17</td>
<td>1.02</td>
<td>0.13</td>
<td>0.05</td>
</tr>
<tr>
<td>3-Aug-16</td>
<td>0.52</td>
<td>0.25</td>
<td>0.05</td>
</tr>
</tbody>
</table>

2.1.2.2 Temperature

Five Sea-Bird SBE-3-Plus temperature transducers #1416, #2454, #2907, #4448, #5519 were available during the 2019 HOT and WHOTS cruises. These were calibrated at Sea-Bird on the dates indicated in Table 2.2.

The history of the sensors, as well as the procedures, followed to obtain the sensor drift from the Sea-Bird calibrations, are well-documented in previous HOT data reports (Fujieki et al., 2013, 2012, 2011, 2010, 2008, 2007, 2006, 2005, Santiago-Mandujano et al., 2002, 2001, 1999, Tupas et al., 1993, 1994a, 1995, 1997, 1998, Karl et al. 1996). Calibration coefficients obtained at Sea-Bird for these sensors after 2018 and used in the drift estimates are presented in Table 2.2. These coefficients were used in the following formula that gives the temperature (in °C) as a function of the frequency signal (f):

\[
\text{temperature} = \frac{1}{a+b[\ln(f_0/f)]+c[\ln^2(f_0/f)]+d[\ln^3(f_0/f)]} - 273.15
\] (1)
Table 2.2: Calibration coefficients for Sea-Bird temperature sensors. RMS residuals from calibration indicate the quality of the calibration.

<table>
<thead>
<tr>
<th>SN</th>
<th>Date</th>
<th>f0</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>RMS (°C)</th>
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<td>1416</td>
<td>200228</td>
<td>6233.97</td>
<td>3.68121040E-03</td>
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<td>6234</td>
<td>3.68120925E-03</td>
<td>6.01682603E-04</td>
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</tr>
</tbody>
</table>

For each sensor, the final calibration consists of two parts: first, a single "baseline" calibration is chosen from among the ensemble of calibrations during the year; second, for each cruise, a temperature-independent offset is applied to remove the temporal trend due to sensor drift (Table 2.3). The offset, a linear function of time, is calculated by a least-squares fit to the 0-30 °C average of each calibration during the year. The maximum drift correction in 2019 was less than 1.1 x 10^-4 °C for the data collected with these sensors. The baseline calibration is selected as the one for which the trend-corrected average from 0-5 °C is nearest to the ensemble mean of these averages.

A small residual pressure effect on the temperature sensors documented in Tupas et al. (1997) has been removed from measurements obtained with our sensors. Another correction to our temperature measurements was for the viscous heating of the sensor tip due to the water flow. This correction is thoroughly documented in Tupas et al. (1997).
Dual sensors were used during each of the 2019 cruises. The temperature differences between sensor pairs were calculated for each cast to evaluate the data's quality and identify possible problems with the sensors. Means and standard deviations of the differences in 2-dbar bins were calculated from the ensemble of all casts at Station ALOHA for each cruise. Both sensors performed correctly during the 2019 cruises, showing temperature differences within expected values. The mean temperature difference as a function of pressure was typically less than $1 \times 10^{-3}$ °C, with a standard deviation of less than $0.5 \times 10^{-3}$ °C below 500 dbar. The largest variability was observed in the thermocline, with standard deviation values of up to $5 \times 10^{-3}$ °C.

Sensor #1416

This sensor was used during all the 2019 cruises. The instrument showed a large offset after the January 2018 calibration. The calibrations from March 2018 through February 2020 yielded a sensor drift of $5.51 \times 10^{-6}$ °C day$^{-1}$, with an intercept of $4.1 \times 10^{-4}$ °C and a RMS residual of $4.4 \times 10^{-4}$ °C, which was used to obtain the drift correction for cruises HOT-309 through HOT-317, and WHOTS-16. When corrected for linear drift to 12 July 2019 (the mid-date when the sensor was used), the 22 March 2019 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 12 July 2019). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 1.6 m°C and were applied to the data (Table 2.3).

Sensor #5519

This sensor was used during all the 2019 cruises except HOT-309. The calibrations after June 2018 showed a change in the sensor drift. Calibrations between November 2018 through February 2020 yielded a sensor drift of $1.63 \times 10^{-6}$ °C day$^{-1}$, with an intercept of $4.7 \times 10^{-5}$ °C and a RMS residual of $7.7 \times 10^{-5}$ °C, which was used to obtain the drift correction for cruises HOT-310 through HOT-317, and WHOTS-16. When corrected for linear drift to 30 July 2019 (the mid-date when the sensor was used), the May 2019 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 30 July 2019). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 0.4 m°C and were applied to the data (Table 2.3).

Sensor #4448

This sensor was used during HOT-309. The calibrations from February 2012 through February 2020 yielded a sensor drift of $9.8 \times 10^{-7}$ °C day$^{-1}$, with an intercept of $1.2 \times 10^{-4}$ °C and a RMS residual of $2.3 \times 10^{-4}$ °C, which was used to obtain the drift correction for cruise HOT-309. When corrected for linear drift to 16 January 2019 (the mid-date when the sensor was used), the October 2019 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 16 January 2019). A drift correction was obtained using this calibration as a baseline. The resulting drift corrections for the cruise were less than 0.3 m°C, as shown in Table 2.3.
Sensor #2907

This sensor was not used during the 2019 cruises. The calibrations from January 2015 through February 2020 yielded a sensor drift of \(-1.1 \times 10^{-8} \, ^\circ\text{C} \, \text{day}^{-1}\), with an intercept of \(3.3 \times 10^{-4} \, ^\circ\text{C}\) and a RMS residual of \(4.8 \times 10^{-4} \, ^\circ\text{C}\).

Sensor #2454

This sensor was not used in 2019. The calibrations from August 2014 through March 2020 yielded a sensor drift of \(9.8 \times 10^{-7} \, ^\circ\text{C} \, \text{day}^{-1}\) for this sensor, with an intercept of \(-7.9 \times 10^{-5} \, ^\circ\text{C}\) and a RMS residual of \(1.5 \times 10^{-4} \, ^\circ\text{C}\).

Table 2.3: Temperature (T) and Conductivity (C) sensor corrections, including the thermal inertia parameter (\(\alpha\)). Dual temperature and conductivity sensors were used in all cruises. The last column indicates which T-C sensor pair’s data is reported.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>T sensor #</th>
<th>T Correction (°C)</th>
<th>C sensor #</th>
<th>(\alpha)</th>
<th>Data reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>1416</td>
<td>-0.000358</td>
<td>4687</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-309</td>
<td>4448</td>
<td>-0.000282</td>
<td>2218</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>HOT-310</td>
<td>1416</td>
<td>-0.000165</td>
<td>4687</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-310</td>
<td>5519</td>
<td>-0.000150</td>
<td>3984</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>HOT-311</td>
<td>1416</td>
<td>0.000232</td>
<td>4687</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-311</td>
<td>5519</td>
<td>-0.000033</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-312</td>
<td>1416</td>
<td>0.000452</td>
<td>4687</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-312</td>
<td>5519</td>
<td>0.000033</td>
<td>3984</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-313</td>
<td>1416</td>
<td>0.000557</td>
<td>3984</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
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<td>2218</td>
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</tr>
<tr>
<td>HOT-314</td>
<td>1416</td>
<td>0.000739</td>
<td>3984</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-314</td>
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<td>0.000117</td>
<td>4687</td>
<td>0.028</td>
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</tr>
<tr>
<td>HOT-315</td>
<td>1416</td>
<td>0.000921</td>
<td>4687</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>HOT-315</td>
<td>5519</td>
<td>0.000171</td>
<td>2959</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>WHOTS-16</td>
<td>1416</td>
<td>-0.001103</td>
<td>4687</td>
<td>0.037</td>
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</tr>
<tr>
<td>WHOTS-16</td>
<td>5519</td>
<td>-0.000225</td>
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<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-316</td>
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<td>0.001158</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-316</td>
<td>5519</td>
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<td>4687</td>
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<td>All Casts</td>
</tr>
<tr>
<td>HOT-317</td>
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<td>0.001500</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
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<td>HOT-317</td>
<td>5519</td>
<td>0.000342</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
</tbody>
</table>

2.1.2.3 Conductivity

Four conductivity sensors were used during the 2019 cruises, including #2218, #2959, #3984, and #4687. Sensor #2218 was sent to Sea-Bird for evaluation in May 2019 after showing large differences against its sensor pair during the deep casts of HOT-309, but nothing wrong was found with the sensor. The sensor was used during HOT-313 and again showed large
differences against its sensor pair. This sensor will be retired. Sensor #4687 showed an offset against its sensor pair during HOT-316 and it was sent to Sea-Bird for evaluation in December 2019, but nothing wrong was found with the sensor. The history of the sensors is well documented in previous HOT data reports (Fujieki et al., 2013, 2012, 2010, 2008, 2007, 2006, 2005, Santiago-Mandujano et al., 2002, 2001, 1999, Tupas et al., 1993, 1994a, 1995, 1997, 1998, Karl et al. 1996). The dual sensor configurations are shown in Table 2.3.

For each sensor, the nominal calibrations were used for data acquisition, and a final calibration was determined empirically from salinities of discrete water samples acquired during each cast. Before empirical calibration, conductivity was corrected for thermal inertia of the glass conductivity cell, as described in Chiswell et al. (1990). Table 2.3 lists the value of the α parameter used for each cruise.

Procedures for preliminary screening of bottle samples and empirical calibration of the conductivity cell are described in Tupas et al. (1993, 1994a). For cruises HOT-309 through -317, the standard deviation cutoff values for screening of bottle salinity samples were: 0.0034 (0-150 dbar), 0.0049 (151-500 dbar), 0.0019 (501-1050 dbar), and 0.0009 (1051-5000 dbar).

The conductivity calibration coefficients \((b_0, b_1, b_2)\) derived from the least-squares fit \((\Delta C = b_0 + b_1C + b_2C^2)\) to the CTD-bottle conductivity differences \((\Delta C)\) as a function of conductivity \((C)\) are given in Table 2.4. None of the cruises required a quadratic calibration. The quality of the CTD calibration is illustrated in Figure 2.2, which shows the differences between the corrected CTD salinities and the bottle salinities used for calibration as a function of pressure for each cruise. The calibrations are best below 500 dbar because the weaker vertical salinity gradients at depth lead to less error when the bottle and CTD pressures are slightly mismatched.

The final step of conductivity calibration was a cast-dependent bias correction described in Tupas et al. (1993) to allow for drift during each cruise or sudden offsets due to fouling (Table 2.5). Note that a change of 1 x 10^-4 Siemens m^-1 in conductivity is approximately equivalent to 0.001 in salinity. Table 2.6 gives the mean and standard deviations for the final calibrated CTD minus bottle samples shown in Figure 2.2.

Conductivity differences between sensor pairs were calculated the same way for temperature sensors (Section 2.1.2.2). The range of variability as a function of pressure was about ± 1 x 10^-4 Siemens m^-1, with a standard deviation of less than 0.5 x 10^-4 Siemens m^-1 below 500 dbar, from the ensemble of all the cruise casts. The largest variability was in the halocline, with standard deviations reaching 5 x 10^-4 Siemens m^-1 between 50 and 300 dbar.
Table 2.4: Conductivity calibration coefficients

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>( b_0 )</th>
<th>( b_1 )</th>
<th>( b_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>4687</td>
<td>0.000398</td>
<td>-0.000112</td>
<td>0</td>
</tr>
<tr>
<td>HOT-309</td>
<td>2218</td>
<td>0.001576</td>
<td>-0.000444</td>
<td>0</td>
</tr>
<tr>
<td>HOT-310</td>
<td>4687</td>
<td>0.000293</td>
<td>-0.000112</td>
<td>0</td>
</tr>
<tr>
<td>HOT-310</td>
<td>3984</td>
<td>0.000596</td>
<td>-0.000064</td>
<td>0</td>
</tr>
<tr>
<td>HOT-311</td>
<td>4687</td>
<td>0.000387</td>
<td>-0.000209</td>
<td>0</td>
</tr>
<tr>
<td>HOT-311</td>
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<td>0.000275</td>
<td>-0.000076</td>
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</tr>
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<td>HOT-312</td>
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</tr>
<tr>
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<td>0.000805</td>
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<tr>
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</tr>
<tr>
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<td>0.000277</td>
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</tr>
<tr>
<td>WHOTS-16</td>
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<td>0.001002</td>
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<td>0</td>
</tr>
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<td>WHOTS-16</td>
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<tr>
<td>HOT-316</td>
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</tr>
<tr>
<td>HOT-316</td>
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</tr>
<tr>
<td>HOT-317</td>
<td>3984</td>
<td>0.000193</td>
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<td>0</td>
</tr>
<tr>
<td>HOT-317</td>
<td>2959</td>
<td>0.000369</td>
<td>-0.000007</td>
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</tr>
</tbody>
</table>

Table 2.5: Individual cast conductivity corrections (units are Siemens m\(^{-1}\))

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Station</th>
<th>Cast</th>
<th>( C ) Correction</th>
</tr>
</thead>
<tbody>
<tr>
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<td>2</td>
<td>2</td>
<td>0.000069</td>
</tr>
<tr>
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<td>15</td>
<td>0.000060</td>
</tr>
<tr>
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<td>1</td>
<td>0.000085</td>
</tr>
<tr>
<td>HOT-310</td>
<td>2</td>
<td>11</td>
<td>0.000018</td>
</tr>
<tr>
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<td>2</td>
<td>2</td>
<td>0.000072</td>
</tr>
<tr>
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<td>15</td>
<td>0.000133</td>
</tr>
<tr>
<td>HOT-312</td>
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<td>2</td>
<td>0.000028</td>
</tr>
<tr>
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<td>15</td>
<td>0.000140</td>
</tr>
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<td>3</td>
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</tr>
<tr>
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<td>-0.000025</td>
</tr>
<tr>
<td>HOT-314</td>
<td>2</td>
<td>2</td>
<td>0.000072</td>
</tr>
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</tr>
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</tr>
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<tr>
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<td>2</td>
<td>14</td>
<td>0.0000255</td>
</tr>
<tr>
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<td>2</td>
<td>-0.0000467</td>
</tr>
<tr>
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<td>0-4700 dbar</td>
<td>500-4700 dbar</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>-------------</td>
<td>---------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>St. dev</td>
</tr>
<tr>
<td>HOT-309</td>
<td>4687</td>
<td>-0.0001</td>
<td>0.0020</td>
</tr>
<tr>
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<td>2218</td>
<td>-0.0001</td>
<td>0.0020</td>
</tr>
<tr>
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<td>4687</td>
<td>-0.0002</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-310</td>
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<td>0.0010</td>
</tr>
<tr>
<td>HOT-311</td>
<td>4687</td>
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<td>0.0017</td>
</tr>
<tr>
<td>HOT-311</td>
<td>2959</td>
<td>-0.0002</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-312</td>
<td>4687</td>
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<td>0.0032</td>
</tr>
<tr>
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</tr>
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<td>0.0000</td>
<td>0.0016</td>
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<td>0.0017</td>
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<td>0.0019</td>
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</tr>
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<td>0.0001</td>
<td>0.0018</td>
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<tr>
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<td>2959</td>
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<td>0.0017</td>
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</tbody>
</table>
2.1.2.4 Oxygen

During the 2019 cruises, our four Sea-Bird SBE-43 oxygen sensors were used: #43262, #431601, #43918, #43982, and a new sensor #433761 acquired in November 2018. The history of these sensors is documented in previous HOT data reports (Fujieki et al., 2013, 2012, 2010, 2008, 2007, 2006, 2005). All these sensors have been calibrated annually at Sea-Bird, and did not show any problems during the 2019 cruises.

Water bottle oxygen data were screened, and the oxygen sensors were empirically calibrated following procedures described previously (Winn et al. 1991; Tupas et al., 1993). The analysis of water bottle samples is described in Section 2.5.1. The calibration procedure follows Owens and Millard (1985) and fits a non-linear equation to the CTD oxygen current and oxygen temperature. The bottle values of dissolved oxygen and the downcast CTD observations at the
potential density of each bottle trip were grouped for each cruise to find the best set of
dparameters with a non-linear least squares algorithm. Two sets of parameters were usually
obtained per HOT cruise, corresponding to the casts at Stations 1 and 2 (calibrations coefficients
from cast 2 are also used to calibrate the casts at stations 6, 50, and 52). The calibration
No oxygen samples were collected during cruise WHOTS-16, which used the same sensors used
during HOT-316; therefore, coefficients from this cruise were used to calibrate WHOTS-16 CTD
oxygen data.

Table 2.7 shows the mean and standard deviation for each cruise's calibrated CTD
oxygen minus water sample residuals. Dual sensors were used during cruises, but only the sensor
whose data were deemed more reliable is reported.

Table 2.7a: CTD-Bottle dissolved oxygen per cruise at Station Kahe (µmol kg⁻¹).

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>43918</td>
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<td>0.67</td>
</tr>
<tr>
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<td>43918</td>
<td>0.00</td>
<td>0.39</td>
</tr>
<tr>
<td>HOT-311</td>
<td>1601</td>
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<td>1.27</td>
</tr>
<tr>
<td>HOT-312</td>
<td>1601</td>
<td>0.00</td>
<td>0.27</td>
</tr>
<tr>
<td>HOT-313</td>
<td>1601</td>
<td>-0.01</td>
<td>0.90</td>
</tr>
<tr>
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<td>1601</td>
<td>0.00</td>
<td>1.12</td>
</tr>
<tr>
<td>HOT-315</td>
<td>43262</td>
<td>0.01</td>
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<tr>
<td>HOT-316</td>
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<td>1.01</td>
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<td>1601</td>
<td>0.00</td>
<td>1.17</td>
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</table>

Table 2.7b: CTD-Bottle dissolved oxygen per cruise at Station ALOHA (µmol kg⁻¹).

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor</th>
<th>0 to 1500 dbar</th>
<th>500 to 4700 dbar</th>
</tr>
</thead>
<tbody>
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<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>HOT-309</td>
<td>43918</td>
<td>0.01</td>
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</tr>
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<td>43918</td>
<td>0.02</td>
<td>0.78</td>
</tr>
<tr>
<td>HOT-311</td>
<td>1601</td>
<td>0.00</td>
<td>0.89</td>
</tr>
<tr>
<td>HOT-312</td>
<td>1601</td>
<td>0.01</td>
<td>0.87</td>
</tr>
<tr>
<td>HOT-313</td>
<td>1601</td>
<td>0.00</td>
<td>0.89</td>
</tr>
<tr>
<td>HOT-314</td>
<td>1601</td>
<td>0.00</td>
<td>0.95</td>
</tr>
<tr>
<td>HOT-315</td>
<td>43262</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>HOT-316</td>
<td>43262</td>
<td>0.00</td>
<td>0.73</td>
</tr>
<tr>
<td>HOT-317</td>
<td>1601</td>
<td>0.02</td>
<td>0.74</td>
</tr>
</tbody>
</table>
2.1.2.5 Fluorescence (Chloropigment)

Fluorescence was measured with a Sea-Point chlorophyll fluorometer (#2440 and #2441). The data was collected using the Sea-Bird CTD system. Fluorescence traces were collected on as many casts as possible. Because an absolute radiometric standard is not available for fluorometers, instrument drift was corrected via calibration with bottle fluorometric chlorophyll a plus accessory pheopigments analyzed using a Turner Designs Model 10-AU fluorometer as described in Section 2.5.7.1. A linear relationship of the form, \( V_{\text{chl}} = b \cdot V_{\text{fluor}} + a \), was used to convert all fluorescence data \( (V_{\text{fluor}}) \) to chloropigment \( (V_{\text{chl}}) \).

2.1.3 Discrete salinity

Salinity samples were collected, stored, and analyzed, as Tupas et al. (1993) described. IAPSO samples were measured to standardize the salinometer, and samples from a large batch of “secondary standard” (substandard) seawater were measured after every 24 to 48 bottle samples of each cruise to detect drift in the salinometer. Standard deviations of the secondary standard measurements were less than ± 0.002 psu for all the cruises (Table 2.8).

The secondary standard seawater batches are made from 60 liters of seawater taken from a depth of 1020 m from Station ALOHA. Three batches of secondary standard seawater were used during 2019. The seawater for Batch #65 water was collected on September 11th, 2018, from S2C11 during the HOT-305 cruise and was made on October 23rd, 2018. Batch #66 had water collected during HOT-307 at S2C10 on November 17th, 2018. This batch was then prepared on December 21st, 2018, and was first used after HOT-312. The last secondary standard seawater, Batch #67, was collected on August 18th, 2019, from S2C11 during HOT-314 and prepared on August 29th, 2019.

Before making each substandard batch, all substandard making materials and supplies were cleaned thoroughly. The plastic and glass carboys used to collect the substandard seawater on the cruise were washed with a non-hazardous buffered alkaline brewery cleaner (Powdered Brewery Wash), an acid-based sanitizer (StarSan), and then rinsed with 99% alcohol before drying.

The glass carboy and glass rod were rinsed with the substandard seawater before being filled and capped with a layer of white oil to prevent oxygenation and evaporation. The filled carboy was then wrapped in black bags to prevent light from reaching the stored substandard seawater.
<table>
<thead>
<tr>
<th>Cruise</th>
<th>Mean Salinity ± SD</th>
<th># Samples</th>
<th>Substandard Batch #</th>
<th>IAPSO Batch #</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>34.4875±0.0006</td>
<td>21</td>
<td>65</td>
<td>P160</td>
</tr>
<tr>
<td>HOT-310</td>
<td>34.4879±0.0004</td>
<td>16</td>
<td>65</td>
<td>P160</td>
</tr>
<tr>
<td>HOT-311</td>
<td>34.4879±0.0003</td>
<td>20</td>
<td>65</td>
<td>P160</td>
</tr>
<tr>
<td>HOT-312</td>
<td>34.4977±0.0018</td>
<td>27</td>
<td>66</td>
<td>P160</td>
</tr>
<tr>
<td>HOT-313</td>
<td>34.4969±0.0003</td>
<td>23</td>
<td>66</td>
<td>P163</td>
</tr>
<tr>
<td>HOT-314</td>
<td>34.4972±0.0003</td>
<td>24</td>
<td>66</td>
<td>P163</td>
</tr>
<tr>
<td>HOT-315</td>
<td>34.4967±0.0002</td>
<td>22</td>
<td>66</td>
<td>P163</td>
</tr>
<tr>
<td>WHOTS-16</td>
<td>34.4955±0.0005</td>
<td>22</td>
<td>67</td>
<td>P163</td>
</tr>
<tr>
<td>HOT-316</td>
<td>34.4955±0.0005</td>
<td>22</td>
<td>67</td>
<td>P163</td>
</tr>
<tr>
<td>HOT-317</td>
<td>34.4910±0.0009</td>
<td>16</td>
<td>67</td>
<td>P163</td>
</tr>
</tbody>
</table>

### 2.2 Thermosalinograph

#### 2.2.1 Data Acquisition

Continuous near-surface salinity and temperature data were collected during every 2019 HOT cruise (HOT-309 through HOT-317) using Sea-Bird thermosalinograph and temperature sensors aboard R/V *Kilo Moana* (KM) and R/V *Oceanus* (OC). The details of each thermosalinograph system varied from ship to ship. Still, each system consisted of a remote temperature sensor measuring near-surface temperature close to the intake of the ship's uncontaminated seawater supply in conjunction with a thermosalinograph sensor that measured both conductivity and temperature further down the seawater supply line. The salinity of seawater was then calculated using the internal temperature and conductivity and the internal pressure of the pump. The 2019 HOT cruises are listed below in Table 2.9, along with the ship used for each cruise and the serial numbers of the Sea-bird sensors used to collect the thermosalinograph data.

Thermosalinograph conductivities were calibrated using bottled salinity samples taken periodically (approximately every 4 hours) from the continuous seawater line outtake near the thermosalinograph. The data from each cruise were also compared with the CTD temperature and conductivity data collected simultaneously and from near the same depth as the seawater supply intake for a final data quality control.
Table 2.9: 2019 HOT Cruise Thermosalinograph Sensors

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Sensor S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>SBE-38</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>External T</em></td>
</tr>
<tr>
<td>HOT-309</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-310</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-311</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-312</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-313</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-314</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-315</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-316</td>
<td>OC</td>
<td>0607</td>
</tr>
<tr>
<td>HOT-317</td>
<td>KM</td>
<td>0150</td>
</tr>
</tbody>
</table>

KM = R/V Kilo Moana  
OC = R/V Oceanus

The thermosalinograph system aboard the R/V *Kilo Moana* consisted of the SBE-38 external temperature sensor (SN 0150) in the bow-thruster chamber in the starboard bow close to the seawater intake. The intake depth was 8 meters below the surface, and the pump's internal pressure was approximately 6 dbar. An SBE-45 Seacat thermosalinograph (SN 0267) measuring internal conductivity and temperature was in the IMET lab at the ship's port bow. Data were acquired every second.

The thermosalinograph system aboard the R/V *Oceanus* comprised an internal SBE-45 Seacat unit (SN 0593) along with an SBE-3 external temperature sensor (SN 0607) located at the seawater intake situated at about 3 m below the sea surface. The external data were acquired once every four seconds but later interpolated to a one-second sample interval to match the thermosalinograph and navigation data time. The internal temperature and conductivity data were obtained every second.

These data were processed and calibrated against bottled salinity samples. Final data for 2019 from cruises aboard R/V *Kilo Moana* are derived from the SBE-45 thermosalinograph at 1-second intervals.
2.2.2 Data processing and sensor calibration

2.2.2.1 Nominal Calibration

2.2.2.1.1 Temperature

The Sea-Bird internal and external temperature sensors (Table 2.9) have been calibrated at Sea-Bird (Table 2.10). These sensors use the following equation and coefficients from Table 2.10 to convert the instrument output (n) to temperature (in °C).

\[
\text{Temperature ITS-90} = \frac{1}{a_0+a_1ln(n)+a_2[ln^2(n)]+a_3[ln^3(n)]}-273.15
\]

Internal SBE-45 sensor #267 was used onboard the R/V Kilo Moana during all the 2019 cruises except HOT-316. The calibrations in Table 2.10 were used to calculate a sensor drift of \(2.35 \times 10^{-7}\) °C day\(^{-1}\). Temperatures were calculated with the 27th May 2015 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than \(4.0 \times 10^{-4}\) °C and inconsequential.

External SBE-38 sensor #150 was used onboard the R/V Kilo Moana during all the 2019 cruises except HOT-316. The calibrations in Table 2.10 were used to calculate a sensor drift of \(1.28 \times 10^{-7}\) °C day\(^{-1}\). Temperatures were calculated with the 3rd February 2018 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than \(1 \times 10^{-4}\) °C and inconsequential.

There were no historic calibrations from the R/V Oceanus sensors 607 and 593 available to calculate a temperature drift.
Table 2.10: Calibration coefficients for Sea-Bird temperature sensors SBE-45 and SBE-38. RMS residuals from calibration indicate the quality of the calibration.

<table>
<thead>
<tr>
<th>SN</th>
<th>Date yymmd</th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
<th>RMS ((m°C))</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>180203</td>
<td>-1.77616800E-04</td>
<td>3.07900600E-04</td>
<td>-4.60708300E-06</td>
<td>2.06391300E-07</td>
<td>0.04</td>
</tr>
<tr>
<td>150</td>
<td>170104</td>
<td>-1.88606400E-04</td>
<td>3.10492500E-04</td>
<td>-4.81083900E-06</td>
<td>2.11735100E-07</td>
<td>0.03</td>
</tr>
<tr>
<td>150</td>
<td>150113</td>
<td>-1.82930400E-04</td>
<td>3.09166900E-04</td>
<td>-4.70791200E-06</td>
<td>2.09073200E-07</td>
<td>0.01</td>
</tr>
<tr>
<td>150</td>
<td>130912</td>
<td>-1.72247600E-04</td>
<td>3.06668200E-04</td>
<td>-4.51299500E-06</td>
<td>2.04037000E-07</td>
<td>0.04</td>
</tr>
<tr>
<td>150</td>
<td>121025</td>
<td>-1.79407100E-04</td>
<td>3.08346000E-04</td>
<td>-4.64410600E-06</td>
<td>2.07418100E-07</td>
<td>0.04</td>
</tr>
<tr>
<td>150</td>
<td>120212</td>
<td>-1.72715300E-04</td>
<td>3.06779000E-04</td>
<td>-4.52199400E-06</td>
<td>2.04252000E-07</td>
<td>0.05</td>
</tr>
<tr>
<td>150</td>
<td>90916</td>
<td>-1.79443400E-04</td>
<td>3.08337300E-04</td>
<td>-4.64184200E-06</td>
<td>2.07313300E-07</td>
<td>0.06</td>
</tr>
<tr>
<td>0267</td>
<td>201029</td>
<td>7.59619500E-05</td>
<td>2.63793500E-04</td>
<td>-1.63106500E-06</td>
<td>1.30306700E-07</td>
<td>0.05</td>
</tr>
<tr>
<td>0267</td>
<td>150527</td>
<td>6.38012100E-05</td>
<td>2.66684800E-04</td>
<td>-1.86026700E-06</td>
<td>1.36368900E-07</td>
<td>0.11</td>
</tr>
<tr>
<td>0267</td>
<td>140410</td>
<td>-2.36766100E-05</td>
<td>2.87190900E-04</td>
<td>-3.46027700E-06</td>
<td>1.77947300E-07</td>
<td>0.14</td>
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<tr>
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<td>130330</td>
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<td>2.77968700E-04</td>
<td>-2.73571000E-06</td>
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<td>2.78775700E-04</td>
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<td>0267</td>
<td>110211</td>
<td>1.15088700E-05</td>
<td>2.78749000E-04</td>
<td>-2.78802000E-06</td>
<td>1.60157500E-07</td>
<td>0.05</td>
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<td>0267</td>
<td>91103</td>
<td>2.46465400E-05</td>
<td>2.75842600E-04</td>
<td>-2.57350400E-06</td>
<td>1.54870500E-07</td>
<td>0.07</td>
</tr>
<tr>
<td>0267</td>
<td>81009</td>
<td>1.87372200E-05</td>
<td>2.77245500E-04</td>
<td>-2.68403000E-06</td>
<td>1.57765100E-07</td>
<td>0.08</td>
</tr>
<tr>
<td>607</td>
<td>190228</td>
<td>6.63253700E-05</td>
<td>2.70166600E-04</td>
<td>-2.15900400E-06</td>
<td>1.43859600E-07</td>
<td>0.00</td>
</tr>
<tr>
<td>593</td>
<td>190315</td>
<td>7.29069900E-05</td>
<td>2.67753900E-04</td>
<td>-1.98570200E-06</td>
<td>1.39608700E-07</td>
<td>0.08</td>
</tr>
</tbody>
</table>

2.2.2.1.2 Conductivity

Two different conductivity sensors were used to collect thermosalinograph data for the 2019 HOT cruises (Table 2.9). All the conductivity data were nominally calibrated with coefficients obtained at Sea-Bird. However, all the final salinity data were calibrated against bottle data, as explained below (Section 2.2.2.3).

2.2.2.2 Processing

The thermosalinograph data were screened for gross errors with upper and lower bounds of 35 and 18 °C for temperature and 6 and 3 Sm\(^{-1}\) for conductivity. There were 6 gross errors detected in temperature during HOT-316; 4 gross errors detected in temperature during HOT-310, -317; 3 gross errors detected in temperature during HOT-309, -310, -313 to -315; 2 gross errors detected in temperature during HOT-311. No other gross errors were detected in temperature or conductivity during the other 2019 HOT cruises. All cruises during 2019 contained around 350,000 1-sec interval data points. The remaining data were subsequently screened for bad or suspicious points and were ascribed to factors such as air bubbles entering the thermosalinograph system, low flow rate, electrical surges from the power supply, biological fouling of the thermosalinograph, the ship being in port, etc. A quality control system has been established so that each temperature and salinity point is given a flag to determine whether the data are good, suspect, or bad. A 21-point running median filter was used to detect one or two-point temperature and conduct glitches in the thermosalinograph data. Glitches in temperature
and conductivity detected by the 21-point median filter were immediately replaced by the median. Threshold values of 0.3 °C for temperature and 0.1 Sm⁻¹ for conductivity were used for the median filter. Typically, no more than a few points per cruise are replaced after running the median filter. A 3-point triangular mean filter was used to smooth the temperature and conductivity data from all the cruises after they had gone through glitch detection. The temperature and conductivity record were manually inspected to further flag suspect or bad data.

After the temperature and conductivity data are processed through the gross error check, median filter, and mean filter, all the temperature (internal and external), conductivity, salinity, speed, and navigation data streams are merged into one set of plots for visual assessment. The merged data are visually inspected for spikes in the data that may have passed through the previous filters. After visually inspecting the remaining data, the number of thermosalinograph data points flagged as suspicious or bad on the other cruises ranged between about 1,200 and 82,000 in 2019. HOT-309 exhibited a total of 75,869 flagged points after the quality control; HOT-310 displayed a similar value of 82,123 flagged points; Fewer points were flagged during HOT-311 and HOT-312, 17,343, and 1208, respectively. HOT-313 showed a total of 14,533 flagged points; HOT-314 exhibited a total of 6,879 flagged points; HOT-315 presented 17,804 flagged points; HOT-316 displayed a total of 14,143 flagged points despite data being collected aboard the R/V Oceanus. Spikes are usually caused by bubbles entering the thermosalinograph system. Strong winds and rough seas (particularly around Ka’ena Point) during transit to ALOHA Station can introduce bubbles resulting in suspect data. The deep seawater intake of R/V Kilo Moana limits these intrusions. Other flagged data resulted from insufficient time allowed for flushing of the uncontaminated seawater line before logging was commenced or because the dataset included data when the ship was in port.

There were some specific problems encountered during the 2019 cruises, which often resulted in sections of data being flagged and are summarized below:

- **HOT-309:** There were two periods during which the thermosalinograph system failed to log the data. The first one was at about 2.6 hours long toward the end of January 16th and the second was about 3.4 hours long on January 17th. These periods were most likely due to internal network issues on the KM. Out of 17 CTD casts conducted while the thermosalinograph was running, 4 casts were removed as temperature or conductivity outliers. Thermosalinograph bottles 1, 4, and 13 were identified as conductivity outliers and removed, while bottles 10, 19, and 22 were removed because the thermosalinograph was not functioning when the sample was taken.

- **HOT-310:** There were three periods during which the thermosalinograph system failed to log data. The first one was ~2.6 hours long on February 20th, the second was ~1.8 hours long on February 21st, and the last one was ~4.6 hours long on February 22nd. These periods were most likely due to internal network issues on the KM. In addition, the thermosalinograph system at one point began trying to record data at 1000Hz instead of 1Hz, which caused problems with the data logging. OTG is aware of these issues. Winds during the cruise were from the NE to E with variable speeds ranging from 5-15 kts for most of the cruise, with winds 25-35 kts for a nine-hour period on February 19th. Sea swell was 6-12 ft. Out of 13 CTD casts, Casts 8, 9, 10, 11, and 13 were removed as temperature or conductivity outliers. Thermosalinograph bottles 20 and 24 were identified as conductivity outliers and removed, while bottles 10, 19, and 22 were removed because the thermosalinograph was not functioning when the sample was taken.
- **HOT-311**: Out of 18 casts, Casts 13, 14, 15, and 16 were removed as temperature or conductivity outliers. Thermosalinograph bottles 1, 4, 8, 12, and 16 were identified as conductivity outliers and removed.

- **HOT-312**: Out of 18 CTD casts, Cast 17 was removed as a conductivity outlier. Thermosalinograph bottle 11 was identified as conductivity outliers and removed.

- **HOT-313**: Out of 18 CTD casts, Casts 3, 17, and 18 were removed as conductivity outliers. Thermosalinograph bottles 3, 23, and 24 were identified as conductivity outliers and removed. Thermosalinograph bottles 3, 23, and 24 were identified as conductivity outliers and removed.

- **HOT-314**: Out of 17 CTD casts, Cast 1 was removed as a conductivity outlier. No thermosalinograph bottles were identified as conductivity outliers.

- **HOT-315**: Out of 18 CTD casts, Cast 1 was identified as a temperature outlier after comparing them against the thermosalinograph data. Casts 16, 17, and 18 were removed as conductivity outliers. Thermosalinograph bottles 1, 2, and 4 were identified as conductivity outliers and removed.

- **HOT-316**: External temperature data were acquired once every four seconds, while internal temperature and conductivity data were acquired every second. External temperature data were interpolated to a one-second sample interval to match the thermosalinograph. The mean difference between CTD and the external temperature sensor was -0.3102°C, much greater than typical cruises about the R/V *Kilo Moana*. According to the Oregon State University Marine Technician group, the *Oceanus*’ remote temperature sensor is adjacent to the bow thruster generator, so some latent heat is absorbed into the superstructure around the sensor. Due to this large difference, an offset of -0.3102°C was applied, and these temperature data were flagged as “suspect” (3). Out of 17 CTD casts, Casts 1 and 7 were identified as temperature outliers after comparing them against the thermosalinograph data. Cast 1 was removed as a conductivity outlier. Thermosalinograph bottles 1, 2, 3, 4, and 5 were identified as conductivity outliers and removed.

- **HOT-317**: Winds measured at the WHOTS buoy near Station ALOHA were from East at about 15 knots during the beginning of the cruise, increasing over 30 knots from the NE by Friday morning. Swell was approximately 15ft feet. Operations were canceled, and the ship returned to port. Out of 8 CTD casts, no outliers were removed from the dataset.

An estimate of the noise in thermosalinograph data was performed to evaluate quality. A 101-point running mean (17 minutes at a 10-second sampling rate) was applied to the thermosalinograph salinities and external temperatures, and the standard deviations of the residuals from the original data were used as an estimate of the data noise. Only data taken during periods of near-constant salinity or temperature were included in the estimates to avoid large residuals resulting in sections of great variability. Noise estimates were obtained for all cruises HOT-309 through 317 (*Table 2.11*).
Table 2.11: Thermosalinograph Data Noise Estimates

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Salinity Noise (psu)</th>
<th>Temperature Noise (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>0.00072</td>
<td>0.0046</td>
</tr>
<tr>
<td>HOT-310</td>
<td>0.00048</td>
<td>0.0030</td>
</tr>
<tr>
<td>HOT-311</td>
<td>0.00046</td>
<td>0.0038</td>
</tr>
<tr>
<td>HOT-312</td>
<td>0.00054</td>
<td>0.0039</td>
</tr>
<tr>
<td>HOT-313</td>
<td>0.00063</td>
<td>0.0033</td>
</tr>
<tr>
<td>HOT-314</td>
<td>0.00050</td>
<td>0.0024</td>
</tr>
<tr>
<td>HOT-315</td>
<td>0.00050</td>
<td>0.0035</td>
</tr>
<tr>
<td>HOT-316</td>
<td>0.00039</td>
<td>0.0051</td>
</tr>
<tr>
<td>HOT-317</td>
<td>0.00059</td>
<td>0.0060</td>
</tr>
</tbody>
</table>

2.2.2.3 Conductivity Calibration

The thermosalinograph salinity was calibrated by comparing it to bottle salinity samples drawn from the plumbing near the thermosalinograph. Bottle salinity samples were analyzed, as described in Section 2.1.3.

The bottle sampling areas aboard both research vessels are located within 1 m of the thermosalinograph used to calculate salinity. Therefore, thermosalinograph data were extracted within ±15 seconds around the bottle sample time.

As in previously reported cruises (Tupas et al., 1997), a cubic spline was fit to the time-series of the differences between the bottle conductivity and the thermosalinograph conductivity separately for all the 2019 HOT cruises. The correction of the thermosalinograph conductivities was obtained from this fit. Salinity was calculated using these corrected conductivities, thermosalinograph temperatures, and the pressure of the pump. The mean values for the salinity bottle minus the final calibrated thermosalinograph were less than ±1 x 10⁻⁵ for all cruises. The mean differences and standard errors for all cruises in 2019 are shown in Table 2.12.

Table 2.12: Bottle-Thermosalinograph Salinity Comparison

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>Mean Difference</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>0267</td>
<td>0.000001</td>
<td>0.000435</td>
</tr>
<tr>
<td>HOT-310</td>
<td>0267</td>
<td>0.000008</td>
<td>0.000473</td>
</tr>
<tr>
<td>HOT-311</td>
<td>0267</td>
<td>0.000004</td>
<td>0.000444</td>
</tr>
<tr>
<td>HOT-312</td>
<td>0267</td>
<td>0.000007</td>
<td>0.000694</td>
</tr>
<tr>
<td>HOT-313</td>
<td>0267</td>
<td>0.000009</td>
<td>0.000678</td>
</tr>
<tr>
<td>HOT-314</td>
<td>0267</td>
<td>0.000010</td>
<td>0.000571</td>
</tr>
<tr>
<td>HOT-315</td>
<td>0267</td>
<td>0.000001</td>
<td>0.000414</td>
</tr>
<tr>
<td>HOT-316</td>
<td>0593</td>
<td>0.000000</td>
<td>0.000239</td>
</tr>
<tr>
<td>HOT-317</td>
<td>0267</td>
<td>0.000013</td>
<td>0.000824</td>
</tr>
</tbody>
</table>
2.2.2.4 Comparison with the CTD Data

The external temperature and the calibrated thermosalinograph salinity data collected during CTD casts were compared with the downcast CTD salinity from 6 dbar (R/V Kilo Moana cruises) and 3 dbar (R/V Oceanus cruise) as additional quality control. This procedure was conducted in the same manner as in previously reported HOT cruises. The thermosalinograph data were averaged using data sampled one minute after the acquisition time of the CTD sample.

Mean thermosalinograph salinity difference with the CTD salinity was smaller than ±2.46 mpsu, except for HOT-311, which displayed a value of -0.006 psu. Mean temperature differences between the CTD and the external temperature sensor were smaller than ±0.03 ºC for all cruises.

Table 2.13: CTD – External Temperature and CTD – Thermosalinograph Salinity

<table>
<thead>
<tr>
<th>Cruise</th>
<th>SBE-38 Ext T Sensor #</th>
<th>CTD-External Temperature (ºC)</th>
<th>SBE-45 Int T + C Sensor #</th>
<th>CTD-Thermosal Salinity (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-309</td>
<td>0150</td>
<td>-0.02023</td>
<td>0267</td>
<td>0.000375</td>
</tr>
<tr>
<td>HOT-310</td>
<td>0150</td>
<td>-0.01130</td>
<td>0267</td>
<td>0.001196</td>
</tr>
<tr>
<td>HOT-311</td>
<td>0150</td>
<td>0.01369</td>
<td>0267</td>
<td>-0.006647</td>
</tr>
<tr>
<td>HOT-312</td>
<td>0150</td>
<td>-0.02951</td>
<td>0267</td>
<td>-0.001832</td>
</tr>
<tr>
<td>HOT-313</td>
<td>0150</td>
<td>0.02701</td>
<td>0267</td>
<td>-0.001599</td>
</tr>
<tr>
<td>HOT-314</td>
<td>0150</td>
<td>-0.01501</td>
<td>0267</td>
<td>-0.000117</td>
</tr>
<tr>
<td>HOT-315</td>
<td>0150</td>
<td>-0.02270</td>
<td>0267</td>
<td>-0.000971</td>
</tr>
<tr>
<td>HOT-316</td>
<td>0607</td>
<td>-0.00003*</td>
<td>0593</td>
<td>0.001309</td>
</tr>
<tr>
<td>HOT-317</td>
<td>0150</td>
<td>-0.02383</td>
<td>0267</td>
<td>-0.002456</td>
</tr>
</tbody>
</table>

KM = R/V Kilo Moana  KOK = R/V Oceanus

*Temperature offset of -0.3102ºC applied to this dataset
2.3 Meteorology

Wind speed and direction, atmospheric pressure, wet- and dry-bulb air temperature, sea surface temperature (SST), cloud cover, and weather code were recorded at four-hour intervals while at Station ALOHA by the science personnel. Continuous wind velocity measurements were recorded at 5-min intervals from the anemometers on the R/V Kilo Moana (21 m height).

Also available were hourly atmospheric pressure, air temperature, SST, wind velocities, and relative humidity measurements from the WHOTS buoy (see Section 2.10). The anemometers in the buoy were 2.7 m above the sea surface.

The time series of shipboard observations obtained by the science group was plotted, and obvious outliers were identified and flagged. The SST-dry air temperature and wet-dry air temperature plots also helped to identify outliers. Outliers in the shipboard pressure, air temperature, SST, and wind observations were detected by comparison with the WHOTS buoy data.

In addition to wind speed and direction (RM Young port and starboard side anemometers), instruments on the R/V Kilo Moana provided measurements of air temperature (RM Young Resistive Temperature Device), relative humidity (Rotronic Instrument Corp. humidity probe), barometric pressure (Vaisala digital barometer), incoming shortwave (Eppley Precision Spectral Pyranometer) and longwave radiation (Eppley Precision Infrared Radiometer), and precipitation (OSI Optical Rain Gauge (ORG) and RM Young), these data were compared against the measurements taken by the WHOTS buoy (see Section 4.10).
2.4 ADCP Measurements

Currents in the upper ocean (0-1200 m) during 2019 were measured using shipboard Acoustic Doppler Current Profilers (ADCP) onboard R/V Kilo Moana.

Onboard ADCP data are collected and preliminarily processed in real-time using the University of Hawaii's CODAS processing system (http://currents.soest.hawaii.edu). This system allows for automatic quality control of the data and real-time graphic display of current profiles and other data products while at sea. Should any ancillary data stream be disrupted at sea or found to be in error, raw data are saved, and a complete re-processing of the data is possible later.

The R/V Kilo Moana was used during HOT-309 through -315 and then -317. The ship is equipped with two ADCP systems. A Teledyne RD Instruments Ocean Surveyor 38 is located on the ship's starboard side, and an RD Instruments WorkHorse 300 is located on the port side; both feature a transducer depth of 7 m. The Ocean Surveyor operates at 38 kHz and can profile to 1200 m in broadband mode (OS38BB) with a bin size of 12 m averaging ensembles every 5 minutes. In narrowband mode (OS38NB) with 24 m bins, profiles can reach as deep as 1500 m. The WorkHorse (WH300) operates at 300 kHz, typically profiling to a maximum of 100 m with a bin size of 2 m and averaging ensembles every 2 minutes. Heading information is taken from the gyrocompass and corrected using a TSS POS/MV 320 (an integrated inertial and GPS). An Ashtech ADU5 is used as a heading-correction device should there be a problem with the POS/MV. Position data are provided by the POS/MV system with an Ashtech ADU5 and a Trimble GPS as backups.

The R/V Oceanus was used during HOT-316. The ship is equipped with a WorkHorse 300 kHz that was enabled to sample to depths of 150 m and bin sizes of 2 m. Ensembles were taken every 2 minutes. This vessel is also equipped with an Ocean Surveyor 75 kHz, configured with bin sizes of 16m, and a sampling interval period of 5 minutes.

Final processing of shipboard ADCP data involves applying small heading corrections to the velocity data based on water track calibrations, trimming unnecessary data from the beginning and ends of the cruise, followed by visual inspection of the final dataset with manual data flagging of suspicious points.

ADCP data were collected using OS38BB, OS38NB, and WH300 onboard R/V Kilo Moana during HOT-310, from HOT-312 to -315, and then on HOT-317. HOT-309 displayed some problems with POS-MV, and OS38BB and OS38NB were not processed. The OS38BB was turned off during the cruise because of an apparent problem with the system.
2.5 Biogeochemical Measurements

At Stations Kahe, ALOHA and Kaena, water samples for chemical analyses were collected from discrete depths using 12 liter PVC bottles with nylon coated internal springs as closing mechanisms. Sampling strategies and procedures are well documented in the previous Data Reports and in the HOT Program Field and Laboratory Protocols manual. This report contains only a subset of the total database, which can be extracted electronically over the Internet (hahana.soest.hawaii.edu/hot/dataaccess.html). To assist in the interpretation of these data and to save users the time to estimate the precision of individual chemical analysis, we have summarized precision estimates from replicate determinations for selected constituents on each HOT cruise in 2019.

2.5.1 Dissolved Oxygen

Dissolved oxygen samples were collected and analyzed using a computer-controlled potentiometric end-point titration procedure as described in Tupas et al. (1997). As in previous years we measured, using a calibrated digital thermistor, the temperature of the seawater sample at the time the iodine flask was filled. This was done to evaluate the magnitude of sample temperature error that affects the calculation of oxygen concentrations in units of µmol kg⁻¹. Figure 2.3 (upper panel) shows a plot of the difference between sample temperature and potential temperature computed from the in situ temperature measured at the time of bottle trip, versus pressure. Figure 2.3 (lower panel) shows a plot of the difference between oxygen concentrations calculated using the sample temperature and potential temperature versus pressure. The depth dependent variability in Δ oxygen is a result of: 1) bottle warming as the rosette is brought up through the water column 2) warm air entering the niskin bottle as samples are being taken and 3) evaporative cooling that occurs while on-deck as bottles are waiting to be sampled.
Figure 2.3: [Upper panel] Difference between sample temperature at the time of sample collection and potential temperature calculated from \textit{in situ} temperature at the time of bottle trip. [Lower panel] Difference in oxygen concentration corrected for temperatures measured at the time of sample collection and potential temperature calculated from \textit{in situ} temperature.
Precision of the Winkler titration method is presented in Table 2.14. The pooled annual mean CV of our oxygen analyses in 2019 was 0.23 %, which was calculated by averaging the mean CV of N-triplicate samples on each cruise. Oxygen concentrations measured over the 31 years of the program are plotted at three constant potential density horizons in the deep ocean along with their mean and 95 % confidence intervals (Figure 2.7 [upper panel]). These results indicate that analytical consistency has been maintained over the past 31 years of the HOT program.

Table 2.14: Precision of Winkler titration method during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Dissolved O$_2$</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µmol/l)</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>309</td>
<td>0.18</td>
<td>0.318</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>310</td>
<td>0.21</td>
<td>0.396</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>311</td>
<td>0.17</td>
<td>0.308</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>312</td>
<td>0.16</td>
<td>0.275</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>313</td>
<td>0.33</td>
<td>0.509</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>314</td>
<td>0.26</td>
<td>0.477</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>315</td>
<td>0.28</td>
<td>0.441</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>0.27</td>
<td>0.449</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>317</td>
<td>0.23</td>
<td>0.375</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td><strong>0.23</strong></td>
<td><strong>0.394</strong></td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
### 2.5.2 Dissolved Inorganic Carbon and Total Alkalinity

Samples for dissolved inorganic carbon (DIC) were measured using a Single Operator Multi-parameter Metabolic Analyzer (SOMMA) which was manufactured at the University of Rhode Island and standardized at the Brookhaven National Laboratory. The pooled annual CV of the DIC analyses during 2019 was 0.02% (Table 2.15). It was calculated by averaging the mean CV of N-duplicate samples on each cruise. Total alkalinity (TA\textsubscript{lk}) was determined using the modified Gran titration method as described in Tupas \textit{et al.} (1997). The pooled annual CV of the TA\textsubscript{lk} analyses during 2019 was 0.07% (Table 2.15).

#### Table 2.15: Precision of DIC and Total Alkalinity analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (µmol kg\textsuperscript{-1})</th>
<th>Mean SD (µmol kg\textsuperscript{-1})</th>
<th>N</th>
<th>Mean CV (%)</th>
<th>Mean SD (µeq kg\textsuperscript{-1})</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>309</td>
<td>0.01</td>
<td>0.318</td>
<td>3</td>
<td>0.06</td>
<td>1.485</td>
<td>3</td>
</tr>
<tr>
<td>310</td>
<td>0.00</td>
<td>0.095</td>
<td>2</td>
<td>0.09</td>
<td>2.192</td>
<td>3</td>
</tr>
<tr>
<td>311</td>
<td>0.03</td>
<td>0.596</td>
<td>3</td>
<td>0.04</td>
<td>0.919</td>
<td>3</td>
</tr>
<tr>
<td>312</td>
<td>0.02</td>
<td>0.431</td>
<td>3</td>
<td>0.03</td>
<td>0.633</td>
<td>2</td>
</tr>
<tr>
<td>313</td>
<td>0.01</td>
<td>0.113</td>
<td>3</td>
<td>0.04</td>
<td>0.966</td>
<td>3</td>
</tr>
<tr>
<td>314</td>
<td>0.04</td>
<td>0.827</td>
<td>3</td>
<td>0.04</td>
<td>0.919</td>
<td>3</td>
</tr>
<tr>
<td>315</td>
<td>0.04</td>
<td>0.907</td>
<td>3</td>
<td>0.14</td>
<td>3.300</td>
<td>3</td>
</tr>
<tr>
<td>316</td>
<td>0.04</td>
<td>0.903</td>
<td>3</td>
<td>0.07</td>
<td>1.603</td>
<td>3</td>
</tr>
<tr>
<td>317</td>
<td>0.02</td>
<td>0.486</td>
<td>3</td>
<td>0.08</td>
<td>1.909</td>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.520</td>
<td>9</td>
<td>0.07</td>
<td>1.547</td>
<td>9</td>
</tr>
</tbody>
</table>

The accuracy of DIC and total alkalinity measurements was established with certified reference materials (CRMs) obtained from Andrew Dickson at Scripps Institution of Oceanography. The time-series of measured differences from the CRM are shown in Figure 2.4 and Figure 2.5.
Figure 2.4: DIC measured difference from certified reference materials (CRMs). The mean (± stdev, n=142) was 0.04 ± 1.24 µmol kg⁻¹.

Figure 2.5: Total alkalinity (TA lk) measured difference from certified reference materials (CRMs). The mean (± stdev, n=329) was -1.53 ± 4.16 µeq kg⁻¹.

2.5.3 pH

All pH data presently being made available were collected using the spectrophotometric method of Clayton and Byrne (1993) and are reported at a constant temperature of 25°C. The +0.0047 unit correction suggested by DelValls and Dickson (1998) has NOT been applied to any HOT data. The 1992-1993 HOT pH data were originally reported on the Seawater Scale, while later data have all been reported on the Total Scale. For the sake of consistency, the 1992-1993 pH data have as of today been converted to the Total Scale according to Lewis and Wallace (1998). The Total Scale values are approximately 0.01 pH units higher than the Seawater Scale.
values they replace. The cruises affected are HOT 36-47 and HOT 49-50. Prior to 1992, on HOT 23-32, pH measurements were made using a pH electrode calibrated with NBS buffers and were reported on the NBS Scale. Potentiometric measurements of pH are inherently less precise than spectrophotometric measurements. Moreover, the relationship between the NBS Scale and the Total Scale is not exact and depends on characteristics of the electrode employed. Given these difficulties, we have not attempted to correct the pre-1992 data to the Total Scale.

The pooled annual CV of the pH analysis during 2019 was 0.020\% (Table 2.16). It was calculated by averaging the mean CV of N-duplicate samples on each cruise. The time-series of measured values at 4500 decibars at Station ALOHA are shown in Figure 2.6.

Table 2.16: Precision of pH analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (Total @ 25°C)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>309</td>
<td>0.020</td>
<td>0.0016</td>
<td>4</td>
</tr>
<tr>
<td>310</td>
<td>0.016</td>
<td>0.0013</td>
<td>4</td>
</tr>
<tr>
<td>311</td>
<td>0.016</td>
<td>0.0013</td>
<td>4</td>
</tr>
<tr>
<td>312</td>
<td>0.026</td>
<td>0.0020</td>
<td>4</td>
</tr>
<tr>
<td>313</td>
<td>0.021</td>
<td>0.0017</td>
<td>4</td>
</tr>
<tr>
<td>314</td>
<td>0.022</td>
<td>0.0017</td>
<td>3</td>
</tr>
<tr>
<td>315</td>
<td>0.020</td>
<td>0.0016</td>
<td>4</td>
</tr>
<tr>
<td>316</td>
<td>0.025</td>
<td>0.0020</td>
<td>4</td>
</tr>
<tr>
<td>317</td>
<td>0.010</td>
<td>0.0008</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>0.020</td>
<td>0.0016</td>
<td>9</td>
</tr>
</tbody>
</table>

pH Quality Control Chart

Figure 2.6: pH measured at 4500 decibars at Station ALOHA. The mean (± stdev, n=94) was 7.582 ± 0.002.
2.5.4 Inorganic Nutrients

2.5.4.1 Standard Autoanalyzer Method

Samples for the determination of dissolved inorganic nutrient concentrations (soluble reactive phosphorus, [nitrate+nitrite] and silicate) were collected as described in Tupas et al. (1993). Up until February 2000, analyses were conducted on a four-channel Technicon Autoanalyzer II continuous flow system at the University of Hawaii Analytical Services Facility. Starting March 2000, samples have been run using a six-channel Bran Luebbe Autoanalyzer III. The average precisions during 2019 from duplicate analyses are given in Table 2.17. Figures 2.7-2.8 show the mean and 95% confidence limits of nutrient concentrations measured at three potential density horizons for the 31 years of the program. In addition to standard automated nutrient analyses, specialized methods (described below) are used to determine concentrations of nutrients that are normally below the detection limits of autoanalyzer methods.

Table 2.17: Precision of Dissolved inorganic nutrient analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>SRP</th>
<th>[Nitrate + Nitrite]</th>
<th>Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µM)</td>
<td>N</td>
</tr>
<tr>
<td>309</td>
<td>0.23</td>
<td>0.006</td>
<td>5</td>
</tr>
<tr>
<td>310</td>
<td>0.35</td>
<td>0.010</td>
<td>6</td>
</tr>
<tr>
<td>311</td>
<td>0.14</td>
<td>0.004</td>
<td>6</td>
</tr>
<tr>
<td>312</td>
<td>0.35</td>
<td>0.010</td>
<td>6</td>
</tr>
<tr>
<td>313</td>
<td>0.10</td>
<td>0.003</td>
<td>6</td>
</tr>
<tr>
<td>314</td>
<td>0.24</td>
<td>0.006</td>
<td>6</td>
</tr>
<tr>
<td>315</td>
<td>0.39</td>
<td>0.011</td>
<td>6</td>
</tr>
<tr>
<td>316</td>
<td>0.20</td>
<td>0.006</td>
<td>6</td>
</tr>
<tr>
<td>317</td>
<td>0.20</td>
<td>0.006</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>0.24</td>
<td>0.007</td>
<td>9</td>
</tr>
</tbody>
</table>
Figure 2.7: Concentrations at potential density horizons of 27.782, 27.758 and 27.675 (approx. 4000m, 3000m and 2000m) at Station ALOHA. The dashed lines indicate the mean while the dotted lines show the upper and lower confidence limits. [Upper panel] Dissolved oxygen. [Lower panel] Nitrate + Nitrite.
Figure 2.8: Concentrations at potential density horizons of 27.782, 27.758 and 27.675 (approx. 4000m, 3000m and 2000m) at Station ALOHA. [Upper panel] Soluble reactive phosphorus. [Lower panel] Dissolved Silicate.
Calibration, Data Reduction and Calculations

The calibration of dissolved inorganic nutrient determinations in the auto-analysis of seawater samples is performed using standard solutions containing dissolved N, P and Si salts. A nutrient stock solution is prepared by dissolving dried (50°C, 48 hr) analytical grade reagent chemicals with DIW in 1 L glass volumetric flasks containing 1 ml of chloroform. Once dissolved, this stock solution is immediately transferred into 1 L HDPE bottles and stored at room temperature in the dark. The reagent chemicals and concentrations are: KH$_2$PO$_4$ (1 mM), KNO$_3$ (1 mM) and Na$_2$SiF$_6$ (1 mM).

Working standards are prepared daily in PMP volumetric flasks using gravimetric dilutions of the nutrient stocks in LNSW. The PMP flasks are thoroughly rinsed with DIW after use. The LNSW is 0.2 µm filtered open ocean surface seawater from Station ALOHA that is kept in the dark at room temperature for at least six months prior to use. This technique provides a mixed standard solution of N, P and Si that is matrix-matched with the seawater samples and any cross-nutrient interference effect should also be accounted for.

Blank corrections

All seawater standard absorbance peaks are corrected for the absorbance of the seawater diluent (LNSW). All seawater sample peaks are corrected for the refractive index absorbance for each unique nutrient detection system. The refractive index corrections represent the increase in absorbance that is due strictly to the presence of dissolved salts in seawater when compared to the DIW baseline. These corrections are determined by running alternating seawater (LNSW) and DIW cups through the auto-analyzer with only non-color producing reagents online. DIW is run through the color producing reagent lines.

Quality Control

Wako CSK’s and OSIL Nutrient Standards are measured in each channel as reference materials to validate sample measurements. The Wako CSK’s are manufactured in 30.5‰ NaCl and are measured directly. The OSIL nutrient standards are manufactured in DIW and diluted using LNSW to the same concentration as the Wako CSK for direct comparison (40 µM for NO$_3$ , 2 µM for PO$_4$, and 100 µM for Si). Due to the high price of the Wako CSK’s, they are run only once per sample run. The OSIL check standards are run twice, once at the beginning and again at the end of each sample run.

Both the Wako and OSIL standards are used as checks of not only the sample analysis, but as checks of each other. Measured reference material values that are more than 2% from the expected concentration of the reference solutions are scrutinized and cross checked with the other reference material to determine if the analysis is correct. In most cases, both reference materials are within the accepted limits.
Figure 2.9: Wako - 2.0 µM in NaCl, measured directly. Literature shows value of CSK can be up to ~7% low return, so concentration ~1.9 is acceptable. Starting 2019, we switched to using KANSO CRMs (plotted in magenta). The KANSO CRMs have a different concentration from the WAKO CRMs. So we normalized it using the formula: \( \text{SRP}_{\text{WAKO}} = \text{SRP}_{\text{KANSO}} \times (1.90/1.74) \) in order to plot them both on the same graph. The mean (± stdev, n=355) was 1.901 ± 0.032 µM.

Figure 2.10: OSIL - 100 µM stock in DIW, diluted in LNSW to be 2 µM. The mean (± stdev, n=757) was 1.987 ± 0.023 µM.
Starting 2019, we switched to using KANSO CRMs (plotted in magenta). The KANSO CRMs have a different concentration from the WAKO CRMs. So we normalized it using the formula: \([\text{[N+N]}_{\text{WAKO}} = \text{[N+N]}_{\text{KANSO}} \times (39.78/24.33)\) in order to plot them both on the same graph. The mean (± stdev, n=324) was 39.764 ± 0.329 µM.

Figure 2.12: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 40 µM. The mean (± stdev, n=677) was 39.767 ± 0.374 µM.
Figure 2.13: Wako - 100.0 µM in NaCl, measured directly. Starting 2019, we switched to using KANSO CRMs (plotted in magenta). The KANSO CRMs have a different concentration from the WAKO CRMs. So we normalized it using the formula: $\text{Sil}_{\text{WAKO}} = \text{Sil}_{\text{KANSO}} \times \frac{100.50}{57.75}$ in order to plot them both on the same graph. The mean ($\pm$ stdev, n=345) was 100.502 $\pm$ 0.684 µM.

Figure 2.14: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 100 µM. The mean ($\pm$ stdev, n=620) was 100.173 $\pm$ 0.754 µM.
Figure 2.15: Wako - 100.0 μM in NaCl, measured directly. Starting 2019, we switched to using KANSO CRMs (plotted in magenta). The KANSO CRMs have a different concentration from the WAKO CRMs. So we normalized it using the formula: $\text{Sil}_{\text{WAKO}} = \text{Sil}_{\text{KANSO}} \times \frac{100.53}{57.75}$ in order to plot them both on the same graph. The mean (± stdev, n=366) was 100.530 ± 0.712 μM.

Figure 2.16: OSIL - 1000 μM stock in DIW, diluted in LNSW to be 100 μM. The mean (± stdev, n=622) was 100.221 ± 0.842 μM.
Special Cases

In the case of SRP, literature shows that the Wako CSK returns lower than the expected concentration (~7%), therefore a measured value of 1.8 µM for a 2µM CSK is considered acceptable, and a higher than 2% difference from the expected 2 µM concentration is accepted. The use of a PO₄ OSIL reference was introduced to have a reference material that produced a more reliable 2 µM concentration result.

In the case of NO₃, the addition of a check standard containing only NO₂ is also analyzed to check the cadmium column efficiency. If the CV of the NO₂ check standard is more than 2% from the expected 40 µM value, the run is aborted and the cadmium column chips are regenerated.

2.5.4.2 Low-Level [Nitrate+Nitrite]

The chemiluminescent method of Cox (1980) as modified for seawater by Garside (1982) was used to determine the [nitrate+nitrite] content of near surface (0-200 m interval) water samples. The limit of detection for [nitrate+nitrite] was approximately 2 nM with a precision and accuracy of ±1 nM (Dore et al., 1996).

Time-series of our LLN check standards are shown in Figures 2.17-2.19. If check standards fall outside their respective control limits the standard curve will be remade until check standards are within their limits.

Figure 2.17: The mean (± stdev, n=133) was 4.09 ± 0.64 nmol L⁻¹.
Figure 2.18: The mean (± stdev, n=135) was $15.98 \pm 1.06 \text{ nmol L}^{-1}$.

Figure 2.19: The mean (± stdev, n=128) was $158.06 \pm 4.06 \text{ nmol L}^{-1}$.
2.5.4.3 Low-Level Soluble Reactive Phosphorus

Low level soluble reactive phosphorus (SRP) concentrations in the euphotic zone were determined according to the magnesium induced coprecipitation (MAGIC) method of Karl and Tien (1992). Typical precision estimates for triplicate determinations of SRP are from 1-3 % with a detection limit of 2 nM. The MAGIC SRP measurement is also corrected for arsenate interference of the molybdenum blue colorimetric procedure (Johnson 1971), unlike the standard autoanalytical method.

Check standards are made by diluting a CSK std (OSIL at 100µM-PO₄) to target concentrations of 50 nM and 100 nM PO₄ respectively in SSW. The dilutions are made gravimetrically on a Mettler 0-160 g balance by pipetting the OSIL (~ 25 µl and 50 µl), record the weight and adding 50 ml of SSW. These are then treated as regular MAGIC samples. Figure 2.20 shows the difference from the expected concentration and that calculated from the absorbance at 880 nm and the standard curve created for each run. Samples to create the standard curve are also made gravimetrically in SSW, but by using an in-house made stock at 100 µM-PO₄.

Potential sources of error are: 1) balance stability  2) variable volume of SSW that contains some PO₄ and 3) spectrophotometer stability.

Figure 2.20 : Difference from expected concentration and that calculated from the absorbance at 880 nm. The mean (± stdev, n=171) was 0.69 ± 1.91 nmol L⁻¹.
2.5.5 Total Organic Carbon

Total organic carbon (TOC) was determined by the high temperature catalytic oxidation method using a Shimadzu TOC-V CSH Total Organic Carbon Analyzer. Prior to HOT-125 (March 2001) TOC concentrations had been measured on a commercially available MQ model 1001 TOC analyzer equipped with a LICOR infrared detector. The average precisions during 2017 from duplicate TOC analyses are given in Table 2.18.

Table 2.18: Precision of Total Organic Carbon analyses of replicate samples during 2017

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (µM)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>289</td>
<td>0.9</td>
<td>0.316</td>
<td>4</td>
</tr>
<tr>
<td>290</td>
<td>2.4</td>
<td>0.876</td>
<td>4</td>
</tr>
<tr>
<td>291</td>
<td>1.5</td>
<td>0.569</td>
<td>4</td>
</tr>
<tr>
<td>292</td>
<td>1.8</td>
<td>0.684</td>
<td>4</td>
</tr>
<tr>
<td>293</td>
<td>1.9</td>
<td>0.729</td>
<td>4</td>
</tr>
<tr>
<td>294</td>
<td>1.9</td>
<td>0.683</td>
<td>3</td>
</tr>
<tr>
<td>295</td>
<td>1.9</td>
<td>0.775</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>1.8</td>
<td>0.662</td>
<td>7</td>
</tr>
</tbody>
</table>

Beginning in 1997, certified TOC reference materials were obtained from J. Sharp (University of Delaware) and D. Hansell (RSMAS, University of Miami) and run each time TOC concentrations were analyzed. UV-oxidized distilled water was used to determine the instrument blank. Figure 2.21 shows the time-series of deep seawater reference material (DSRM) obtained from RSMAS used to validate sample measurements. If a value is outside control limits, the run is deemed questionable, and the samples are rerun.
Figure 2.21: Values were obtained from DSRM from the RSMAS Consensus Reference Materials (CRM) Project. The accepted range of the DSRM is 41-44 µM. The DSRM is used to verify the standard dilution curve used to calibrate each sample run. The mean (± stdev, n=32) was 43.45 ± 1.38 µM.

2.5.6 Particulate Bioelements

2.5.6.1 Particulate Carbon and Nitrogen

Samples for elemental analyses of Particulate carbon (PC) and nitrogen (PN) were prefiltered through 202 µm Nitex mesh to remove large zooplankton and collected onto combusted glass fiber filters (Whatman GF/F, 25 mm diameter). They were analyzed using an Exeter Analytical CE-440 CHN elemental analyzer. This instrument combines the classical Pregal and Dumas methods for the determination of PC and PN, respectively. The samples are combusted in pure O\textsubscript{2} under static conditions and the by-products are measured by a series of high precision thermal conductivity detectors each containing a pair of thermal conductivity cells (P.E.Hemming, Exeter Analytical (UK) Ltd). During the course of the analytical run a maximum of 8 samples are analyzed followed by a blank, check standard (acetanilide) and secondary standard (plankton).

The average field variability between duplicate analyses during 2019 are presented in Table 2.19. Figure 2.22a shows the time-series of the acetanilide check standard and Figure 2.22b shows the time-series of our in-house plankton secondary standard. Two batches of plankton standards have been used during the course of the time-series. The old batch was used from HOT 166-264 (Sep 2005 - Aug 2014). While the new batch was used starting from HOT-249 (Mar 2014). The old plankton standard is shown in cyan, while the new standard is plotted in magenta. Should the PC/PN ratio of the plankton fall outside the control limits the analytical run is terminated.
Table 2.1: Field variability of Particulate carbon and nitrogen analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>PC</th>
<th>PN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µg l⁻¹)</td>
</tr>
<tr>
<td>309</td>
<td>6.3</td>
<td>1.032</td>
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<td>310</td>
<td>5.8</td>
<td>0.972</td>
</tr>
<tr>
<td>312</td>
<td>2.6</td>
<td>0.601</td>
</tr>
<tr>
<td>313</td>
<td>3.6</td>
<td>0.824</td>
</tr>
<tr>
<td>314</td>
<td>5.7</td>
<td>1.092</td>
</tr>
<tr>
<td>315</td>
<td>2.4</td>
<td>0.463</td>
</tr>
<tr>
<td>316</td>
<td>9.2</td>
<td>1.640</td>
</tr>
<tr>
<td>317</td>
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<td>0.262</td>
</tr>
<tr>
<td>Mean</td>
<td>4.7</td>
<td>0.861</td>
</tr>
</tbody>
</table>

Figure 2.2a: PC/PN ratios obtained using acetanilide check standard. The mean (± stdev, n=289) was 8.03 ± 0.22.
Figure 2.22b: PC/PN ratios obtained using an in-house plankton secondary standard. The secondary standard is used to verify the independently made standard curve used in each analytical run. The mean ($\pm$ stdev, n=298) was 4.84 ± 0.15. Two batches of plankton standards have been used during the course of the time-series. The 1\textsuperscript{st} batch is shown in cyan. While the 2\textsuperscript{nd} is plotted in magenta.

2.5.6.2 Particulate Phosphorus

Samples for elemental analyses of Particulate phosphorus (PPO$_4$) were prefiltered through 202 $\mu$m Nitex mesh to remove large zooplankton and collected onto combusted, acid washed glass fiber filters (Whatman GF/F, 25 mm diameter). Samples were analyzed using high temperature ashing followed by acid hydrolysis and subsequent determination of the liberated orthophosphate by colorimetry. These procedures are detailed in Karl et al. (1991). The average field variability between duplicate analyses during 2019 are presented in Table 2.20.
Table 2.20: Field variability of Particulate phosphorus analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (µg l⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>309</td>
<td>3.4</td>
<td>0.014</td>
<td>2</td>
</tr>
<tr>
<td>310</td>
<td>9.6</td>
<td>0.028</td>
<td>2</td>
</tr>
<tr>
<td>311</td>
<td>1.5</td>
<td>0.007</td>
<td>2</td>
</tr>
<tr>
<td>313</td>
<td>5.8</td>
<td>0.028</td>
<td>2</td>
</tr>
<tr>
<td>314</td>
<td>7.7</td>
<td>0.021</td>
<td>1</td>
</tr>
<tr>
<td>315</td>
<td>13.7</td>
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<tr>
<td>317</td>
<td>4.9</td>
<td>0.014</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>6.7</td>
<td>0.022</td>
<td>8</td>
</tr>
</tbody>
</table>

Apple leaves (0.159% P by weight; NIST 1515) were used as a check standard for the recovery of particulate organic phosphorus (PPO₄). A known amount of the std material was placed on a GF/F filter and treated as a sample. Figure 2.23 shows the recovery of PPO₄ as reported as the percent of the expected amount of phosphorus in the sample. It is known that 5-10% of the DOP is not recovered from apple leaves during acid hydrolysis which could account for the difference in recovery.

Figure 2.23: Recovery of PPO₄ as a percentage of the expected amount. The mean (± stdev, n=222) was 91.24 ± 3.95.
Analysis Comparison and Protocol Modification

The routine HOT protocol, in use for at least the past decade, involves combustion of particulate material collected on a GF/F filter placed inside an acid cleaned, combusted glass test tube (4 hours at 500°C). Following combustion, 10 ml of 0.15 N HCl is added and the sample centrifuged for 30 min at 1000 xg. A 5 ml aliquot, sampled from the bottom of the tube, is removed and placed into a clean polyethylene tube. The color forming reagent mixture is added (500 µl reagent mix to 5 ml sample) and the sample mixed by vortex and allowed to develop for 1 hour at RT. The sample absorbance is then read at 880 nm in a 1 cm cuvette cell on a Beckman DU-640 spectrophotometer.

In 2011, it was found that the remaining 5 ml volume in the glass tube yielded 2-3x higher concentrations than the first aliquot. A series of tests were conducted, including; increasing the leaching time of the filters in acid from 30 to 60 min, leaching at +60°C for 60 min, and vortex mixing the tube containing the filter and 10 ml 0.15N HCl prior to leaching for 60 min.

The conclusion was that the routine HOT protocol was underestimating the PPO concentration of the sample, and that this most likely was due to either insufficient time to leach P off the filter matrix, or the sample heterogeneous. Heating the sample did not result in additional PPO measured compared to a longer leach time and mixing (Figure 2.24a).

In order to assess leach time alone (treatment 1) versus vortex mixing + leach time (treatment 2), a time course sub-sampling was conducted. Samples consisted of PPO collected on GF/F filters from 25 m at Station ALOHA, apple leaves (NIST 1515), and blank filters. The apple leaves were expected to return 51 nM-P.
Figure 2.24a: Comparing treatments for PPO₄ determinations. 1 - current HOT protocol, 1a, the first aliquot out of 10 ml, 1b is the second aliquot from treatment 1. The ‘combined1’ is the concentration derived from the two aliquots 1a and 1b. Treatment 2 – leaching at 60°C, 60 min and treatment 3 – leaching at RT, 60 min and vortex mixing.

All concentrations were corrected for changes in the filter blanks for each time point and treatment as well as differences in subsample concentration.

For both the water column and apple leaves treatment 2 reached a stable concentration within 30 min whereas treatment 1, with the passive leaching, was more variable with relatively low concentrations after 30 minutes (Figure 2.24b). For the known concentrations of the apple leaves, both treatments reached the same final and expected concentration. Blank filters also showed increased absorbance with leach time, but remained low relative to the samples.

It was concluded that both mixing and leach time influences the extraction of the filters and that vortex mixing reduces the time necessary to fully extract the filters.
It was determined that HOT samples should be run using the modified protocol based on leaching in 0.15N HCl for 60 min, mixing by vortex and centrifuged 30 min to remove any filter debris before subsampling into new tubes for the colorimetric reaction. It was further decided that one year’s worth of HOT samples (water column profiles and sediment trap samples: Figure 2.24c, Figure 2.24d) should be run using the routine HOT protocol and that the second aliquot also should be analyzed to obtain the total P on the filters (i.e. the “combined” concentrations) in order to have overlapping data of the two protocols before transitioning to the modified protocol.

Figure 2.24b: Final concentrations for A) seawater (25 m) samples and B) apple leaf samples for treatments 1 (passive leach) and treatment 2 (vortexed and leached.) C) shows the absorbance values for blank filters over time, uncorrected for any dilutions.
Figure 2.24c: Comparison of the “routine” versus “modified” HOT PPO₄ protocol on sediment trap samples (150 m). Note the grey circles in the lower panel for the new protocol are uncertain as the absorbance for the second aliquot subsample was out of range for the std curve.
Figure 2.24d: Comparison of the “routine” versus “modified” HOT PPO₄ protocol on water column samples (integrated 0-100 m).
2.5.6.3 Particulate Biogenic Silica

Samples for elemental analyses of Particulate biogenic silica (PSi) were collected into 4L polyethylene carboys; filtered through 47 mm polycarbonate filter holders; onto 47 mm polycarbonate, membrane filters; and placed into 50 ml polypropylene centrifuge tubes. Time course subsamples (1.5, 3, 4.5, 6.5 and 24 hours) were measured colorimetrically to distinguish Lithogenic-Si from Biogenic-Si (Brzezinski and Nelson 1989 DSR 1 36: 1009 and 1995 DSR 1 42: 1215). The average field variability between duplicate analyses during 2019 are presented in Table 2.21.

Table 2.21: Field variability of Particulate biogenic silica analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (nmol l⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>309</td>
<td>9.6</td>
<td>1.400</td>
<td>2</td>
</tr>
<tr>
<td>310</td>
<td>20.1</td>
<td>4.426</td>
<td>2</td>
</tr>
<tr>
<td>311</td>
<td>14.6</td>
<td>3.175</td>
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<td>312</td>
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<td>1.750</td>
<td>2</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>317</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>11.9</td>
<td>2.688</td>
<td>4</td>
</tr>
</tbody>
</table>
**2.5.7 Pigments**

**2.5.7.1 Standard Fluorometric Method**

Samples for chlorophyll a (chl a) and pheopigments were collected onto uncombusted glass fiber filters (Whatman GF/F, 25 mm diameter) and measured fluorometrically on a Turner Designs Model 10-AU fluorometer with 100% acetone as the solvent using standard techniques (Strickland and Parsons 1972). It is known that this method will underestimate chlorophyll a in the presence of chlorophyll b (Welschmeyer 1994). The average precisions during 2019 determined from triplicate analyses are presented in Table 2.22.

Table 2.22: Precision of Fluorometric Chlorophyll a and Pheopigment analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Chlorophyll a</th>
<th></th>
<th>Pheopigments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µg l⁻¹)</td>
<td>N</td>
<td>Mean CV (%)</td>
</tr>
<tr>
<td>309</td>
<td>2.8</td>
<td>0.003</td>
<td>6</td>
<td>5.7</td>
</tr>
<tr>
<td>310</td>
<td>5.8</td>
<td>0.008</td>
<td>4</td>
<td>4.4</td>
</tr>
<tr>
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<td>0.008</td>
<td>6</td>
<td>2.3</td>
</tr>
<tr>
<td>312</td>
<td>3.2</td>
<td>0.003</td>
<td>6</td>
<td>5.6</td>
</tr>
<tr>
<td>313</td>
<td>5.1</td>
<td>0.004</td>
<td>5</td>
<td>5.7</td>
</tr>
<tr>
<td>314</td>
<td>19.8</td>
<td>0.007</td>
<td>7</td>
<td>13.4</td>
</tr>
<tr>
<td>315</td>
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<td>0.005</td>
<td>6</td>
<td>8.5</td>
</tr>
<tr>
<td>316</td>
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<td>6</td>
<td>18.2</td>
</tr>
<tr>
<td>317</td>
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<td>0.003</td>
<td>6</td>
<td>4.8</td>
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<tr>
<td>Mean</td>
<td>7.4</td>
<td>0.006</td>
<td>9</td>
<td>7.6</td>
</tr>
</tbody>
</table>
2.5.7.2 High Performance Liquid Chromatography

Chlorophyll $a$ and photosynthetic accessory pigments were also measured by high performance liquid chromatography (HPLC) according to Wright et al. (1991). The response factors yielded by this method during 2018 are presented in Table 2.23. Figure 2.25 shows the relationship between chlorophyll $a$ measured by fluorometry and chlorophyll $a$ measured by HPLC during 2018.

Table 2.23: 2018 HPLC Pigment analysis Response factors

<table>
<thead>
<tr>
<th>Pigment</th>
<th>RF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll c &amp; Mg 3,8D*</td>
<td>1.0434</td>
</tr>
<tr>
<td>Peridinin</td>
<td>2.2733</td>
</tr>
<tr>
<td>19'-Butanoyloxyfucoxanthin</td>
<td>1.4719</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>1.4911</td>
</tr>
<tr>
<td>19'-Hexanoyloxyfucoxanthin</td>
<td>1.5424</td>
</tr>
<tr>
<td>Prasinoxanthin</td>
<td>1.7480</td>
</tr>
<tr>
<td>Violaxanthin</td>
<td>1.0332</td>
</tr>
<tr>
<td>Diadinoxanthin</td>
<td>1.1504</td>
</tr>
<tr>
<td>Alloxanthin</td>
<td>1.1741</td>
</tr>
<tr>
<td>Lutein</td>
<td>1.2558</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>1.3158</td>
</tr>
<tr>
<td>Chlorophyll b</td>
<td>4.1184</td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>2.5968</td>
</tr>
<tr>
<td>$\alpha$-Carotene</td>
<td>1.1391</td>
</tr>
<tr>
<td>$\beta$-Carotene</td>
<td>1.1684</td>
</tr>
</tbody>
</table>

*Chlorophyll c = ($c_1 + c_2 + c_3$), Mg 3,8D = Mg 3,8 divinyl pheoporphyrin a$_5$ monomethyl ester.
Figure 2.25: Chlorophyll a measured by fluorometry (Chla F) versus chlorophyll a measured by HPLC (Chla HPLC) for all data collected in 2018. The black line shows the 1:1 x-y relationship while the red line is a model II linear regression analysis of the data set. The regression equation is at the top of the figure.
2.5.8 Adenosine 5′-triophosphate

The amount of living microbial biomass in the water column was determined by the measurement of adenosine 5′-triphosphate (ATP) concentrations. Seawater samples were filtered through glass fiber filters (Whatman GF/F, 47 mm diameter) to collect particulate material and the filters placed in boiling Tris-buffer for ATP extraction. ATP concentrations were measured on a Turner Luminometer using the firefly bioluminescence technique described by Karl and Holm-Hansen (1978).

The average field precision of Particulate ATP determinations during 2019 derived from triplicate analyses are presented in Table 2.24. Figure 2.26 shows the time-series of our in-house check standard. Should the mean result of the calculated check standard value fall outside the control limits, a new dilution curve will be made and the check standard remeasured against the new curve.

Table 2.24: Precision of Particulate ATP analyses during 2019

<table>
<thead>
<tr>
<th>HOT</th>
<th>Particulate ATP</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (ng l⁻¹)</td>
<td>N</td>
</tr>
<tr>
<td>309</td>
<td>18.5</td>
<td>2.777</td>
<td>9</td>
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<td>310</td>
<td>16.6</td>
<td>3.406</td>
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<td>9</td>
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<td><strong>Mean</strong></td>
<td><strong>14.5</strong></td>
<td><strong>2.980</strong></td>
<td><strong>8</strong></td>
</tr>
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</table>
Figure 2.26: Values obtained using an in-house check standard at 5 ng ATP/ml. The check standard is used to verify the independently made standard curve dilution series used in each analytical run. The mean (± stdev, n=112) was 4.850 ± 0.265 ng ml⁻¹.

2.6 Biogeochemical Rate Measurements

2.6.1 Primary Production

Photosynthetic production of organic matter was measured by the $^{14}$C tracer method. All incubations from 1990 through mid-2000 were conducted in situ at eight depths (5, 25, 45, 75, 100, 125, 150 & 175m) over one daylight period using a free-drifting array as described by Winn et al. (1991). Starting HOT-119 (October 2000), we collected samples from only the upper six depths & modeled the lower two depths based on the monthly climatology. During 2019, all incubations were conducted in situ on a free-floating, surface tethered array. Integrated carbon assimilation rates were calculated using the trapezoid rule with the shallowest value extended to 0 m and the deepest extrapolated to a value of zero at 200 m.

2.6.2 Particle Flux

Particle flux was measured at a standard reference depth of 150 m using multiple cylindrical particle interceptor traps deployed on a free-floating array for approximately 60 h during each cruise. Sediment trap design and collection methods are described in Winn et al. (1991). Samples were analyzed for particulate C, N, PO₄ and Si as described in Section 2.5.6 above. Typically six traps are analyzed for PC and PN, three for PPO₄, and another three traps for PSi.
2.7 Optical Measurements

2.7.1 Solar Irradiance

Incident irradiance (400-700 nm wavelength band) at the sea surface was measured on each HOT cruise with a LI-COR LI-1500 data logger and cosine collector. The instrument recorded data from the time the ship departed the University of Hawaii Marine Center until its return.

2.7.2 Downwelling Irradiance and Upwelling Radiance (HyperPro)

The Satlantic HyperPro is an in-situ free-fall profiling unit designed to measure the apparent optical properties of the ocean with concurrent measurements of temperature, salinity, chlorophyll and dissolved matter fluorescence, and optical backscattering (a proxy for total particle load). The unit is equipped with one up-looking and one down-looking hyperspectral (350-800nm) radiometer with 10 ± 0.3 nm resolution, a WET Labs ECO-Puck Triplet, and temperature, pressure, and conductivity sensors. It also incorporates a ship-mounted surface (air) hyperspectral radiometer. The applications for this sensor include bio-optical algorithm development, satellite calibration and validation, and environmental monitoring. The data products include water leaving radiance, remote sensing reflectance, energy fluxes, and PAR.

2.7.3 Laser In-Situ Scattering and Transmissometry (LISST-100X)

Forward light scattering can be used for rapid determination of in situ particle size distribution and particle concentration based on an inversion of the volume scattering function at small forward angles. One advantage of this technique is that it can capture continuous (1-Hz) in situ data. The LISST-100X measures the near-forward angular scattering distribution between 0.0017 to 0.34 radians (0.097-19.48°; Type-B), at 670 nm, which is a region where scattering is strongly influenced by particle size. Using Mie scattering theory, the LISST estimates a volumetric particle size distribution (V(Dₖ) in units of mL L⁻¹) for 32 logarithmically spaced size classes with geometric mean diameters (Dₖ) ranging from 1.36 - 230.14 mm (for spherical particles). The shape of the PSD is based on an inversion of the angular pattern of forward scattering, and the concentration of particles is derived by the magnitude of scattering that reaches the detector.

Before the measured light scattering distribution is inverted to obtain the particulate volume distribution, the signal must be corrected for background scattering due to pure water. After the inversion the data are corrected for the difference in laser power between the factory calibration and the in situ data, and an instrument-specific correction factor is applied to obtain the calibrated particle volume concentration, in volume particles per volume of water. The areal size distribution (A(Dₖ)) is then calculated from the volume size distribution (µL L⁻¹) by assuming spherical geometry: A(Dₖ) = 3/2 V(Dₖ)Dₖ⁻¹. The mean particle size (D_{AVG}), the slope of the particle size distribution, and the total particle number ($\Sigma$ 1.36mm - 230.14mm size classes) can then be calculated.
2.8 Microbial Community Structure

From December 1990 through September 2005 (HOT 22 - 173), analysis of microbial numbers was made using an EPICS 753 flow cytometer (Coulter Electronics Corporation, Hialeah, FL, USA) upgraded with a Cicero Data Acquisition System (Cytomation Inc., Boulder, Colorado). Prior to analysis by flow cytometry, samples were prepared using standard protocols (Monger & Landry 1993; Campbell et al., 1994). Enumeration efficiency was tracked using fluorescent beads.

Picolankton enumeration data collected after HOT 174 were analyzed using a B/D Influx flow cytometer. Three separate chlorophyll containing populations were enumerated by autofluorescence: Prochlorococcus, Synechococcus and the pico-Eukaryotes. Heterotrophic bacteria were enumerated using the DNA stain SYBR Green I and subtracting the previously obtained Prochlorococcus concentration from the DNA positive cells.

No adequate marine reference materials exist for flow cytometry. Samples for estimating inter-analysis variations were collected during HOT-281 at Station ALOHA and preserved from both the Deep Chlorophyll Maximum (DCM) and the surface (5 decibars). Several samples from each batch were analyzed each day of analysis. Precision percentages were calculated for both depths for each cell-type (Figures 2.27 - 2.30). Prochlorococcus in shallow samples are normally difficult to resolve and the precision associated with the counts of these cells represents this methodic limitation. Samples from the DCM and beyond are easily resolved and the precision values on these counts more closely indicate instrument variability.

![Surface Prochlorococcus Quality Control Chart](image)

Figure 2.27: Prochlorococcus measured at 5 decibars at Station ALOHA. The mean (± stdev, n=469) was $1.696 \times 10^5 \pm 0.090 \times 10^5$ # ml$^{-1}$. 
Figure 2.28: *Prochlorococcus* measured at the DCM at Station ALOHA. The mean (± stdev, n=474) was $6.712 \times 10^4 \pm 0.247 \times 10^4$ # ml$^{-1}$.

Figure 2.29: Heterotrophic Bacteria measured at 5 decibars at Station ALOHA. The mean (± stdev, n=464) was $5.472 \times 10^5 \pm 0.256 \times 10^5$ # ml$^{-1}$.
2.9 Zooplankton Community Structure

2.9.1 Mesozooplankton Collection

Two net systems have been used for routine time-series collections of zooplankton at Station ALOHA. From 1994 to 2005 (Cruises 50-175), we used a 1-m² single-net frame with wire attachments and weighting similar to a MOCNESS (Landry et al., 2001; Sheridan & Landry, 2004). A flow meter with a low-speed rotor (Model 2030R, General Oceanics, Miami, FL) was attached across the net opening to measure distance towed, and a temperature-pressure data logger (Model XL-200, Richard Brancker Research, Ottawa, Canada) was fastened to the net frame to measure depth of tow. From cruise 175 to present, the collection procedure was simplified by switching to a 1-m² diameter ring net, with GO 2030R flow meter and Vemco minilog Time-Depth Recorder. Both frames are fitted with 202-µm filter mesh nets with similar aspect ratios, and they have roughly comparable mouth areas under tow. They are lowered to depth and returned to the surface similarly (by capstan). The main difference is a preceding bridle on the ring net, which may be easier to avoid by larger animals with fast escape responses compared to the side bridles of the original rectangular net. As reported by Valencia et al. (2018), the two net systems were compared in a series of tows on the same cruise, revealing no significant differences in areal estimates of mesozooplankton biomass for either day or night tows (Mann-Whitney test, p > 0.05). They are therefore assumed to be equally efficient samplers in the time series. Since even very large, fast-towed nets (7.3 m² Isaacs-Kidd mid-water trawl and 96 m² Cobb nets; 2-4 kts) are unlikely to sample micronekton quantitatively (Kuba, 1970), neither of the small HOT nets is assumed to capture this fraction well.
2.9.2 Sample Processing

At the end of the tow, the outer side of the net is sprayed down with surface seawater to concentrate the animals in the collecting bucket. As soon as possible after collection, the sample is split using a Folsom plankton splitter. Subsamples are taken for preservation and size-fractionationed biomass. Half of the tow is preserved in borate-buffered formaldehyde (0.5% final concentration), with strontium chloride (0.27 mM final concentration) added to aid in preservation of acantharians. The samples are stored in borosilicate-glass jars. Generally 1/4 of the tow is size-fractioned through nested filters of the following mesh sizes: 5-mm, 2-mm, 1-mm, 500-µm, and 200-µm. Each fraction is concentrated onto a 47-mm 200-µm pre-weighed Nitex filter, rinsed with isotonic ammonium formate, placed in a labeled cryotube, and then frozen (liquid nitrogen or -80°C freezer).

Frozen samples are stored at -85°C until processed. Then, they are defrosted at room temperature in the dark on a paper towel to blot excess moisture. Each sample (which represents a single size-fraction of the tow) is weighed wet on an analytical balance before (total fraction wet weight) and after subsamples of the zooplankton mass are set aside for gut pigment analysis and carbon/nitrogen biomass. The remaining sample is dried at 60°C, and then reweighed for determination of the fraction’s mass (total sample mass is the sum of all fraction masses). The mass of the sample is normalized to the ocean surface area using the volume of seawater filtered through the net as recorded by the flow meter (= volume filtered) and the depth to which the net fished as recorded by the data logger (= depth).

Carbon and nitrogen biomass are determined using a CHN Elemental Analyzer (Perkin Elmer Model 2400) on subsamples which have been dried at 60 °C in pre-weighed combusted aluminum foil boats and then weighed on an analytical balance (to 5-places). The dry weight of the sample is the difference between the final balance weight (sample + boat weight) and the pre-weighed boat weight.

2.10 WHOTS Mooring

The WHOTS-15 mooring was deployed at Station 50 on September 23rd, 2018, 01:17 UTC at 22° 45.94 'N, 157° 53.70 'W, during the WHOTS-15 cruise (September 21st and September 29th, 2018) onboard the NOAA ship Hi’ialakai and was recovered during the WHOTS-16 cruise on October 8th, 2019, onboard the NOAA ship Oscar Sette. Details of the instrumentation (Figure 2.31) and deployment are on the project’s website (http://www.soest.hawaii.edu/whots). Briefly, a Surlyn foam surface buoy was outfitted with two complete sets of ASIMET sensors on the buoy and underneath subsurface instruments from 7 to 155 m depth and near the bottom. The buoy tower also contains a radar reflector, two marine lanterns, and Iridium satellite transmission systems that provide continuous buoy position monitoring. A Xeos Melo Global Positioning System (GPS) receiver, an SBE-39 temperature sensor adapted to measure air temperature, and a Vaisala WXT-520 multi-variable (temperature, humidity, pressure, wind, and precipitation) were also mounted on the tower. A fourth positioning system (Xeos Sable transmitter) was mounted beneath the hull. Several other instruments were mounted on the buoy. A Battelle pCO₂ system, a pumped SBE-16 CTD, and a SAMI-2 pH sensor were mounted to the buoy's underside. A Sea-Bird SBE-63 hosted a dissolved oxygen sensor. Three down-looking radiometers were mounted on the buoy. One
A hyperspectral sensor is mounted facing upward near the radiometers as a reference for the incoming spectral irradiance. A Wetlabs ECOFLNTUS chlorophyll fluorometer was also mounted on the buoy hull.

Five internally logging Sea-Bird SBE-56 temperature sensors were bolted to the buoy hull's underside, measuring sea surface temperature (SST) and salinity. The SBE-56s measured SST once every 60 sec between 80-110 cm below the surface, and two SBE-37 MicroCATs were at 1.52 m.

Underwater instrumentation included 18 Microcats (SeaBird SBE-37) deployed to record temperature and conductivity (C-T) at 7, 15, 25, 35, 40, 45, 50, 55, 65, 75, 85, 95, 105, 120, 135, 155, and two at 38 m off the bottom. The MicroCATs at 7, 45, 85, 105, 120, 135, and 155 m included a pressure sensor and two MicroCATs that were placed 39-14 m off the bottom. Two upward-looking RDI ADCPs were deployed at 47.5 m (600 kHz), and 125 m (300 kHz), respectively, and two Next Generation Vector Measurement Current Meters (VMCMs) were deployed at 10 and 30 m, respectively, to measure current speed and direction.

Details about instruments deployed in the WHOTS-15 mooring and data processing are available in the mooring data report (Pacheco et al., 2020), and a description of the mooring deployment/recovery cruises can be found in the cruise reports (Santiago-Mandujano et al., 2018, 2021). The conductivity/temperature instruments (C-T) are factory calibrated before each deployment, and inter-comparisons with CTD data from HOT and WHOTS deployment/recovery cruises as well as inter-comparisons with the other mooring’s C-Ts are used to correct for sensor’s drift and data quality control. The ADCPs compasses are calibrated before and after each deployment, and the data are inter-compared and quality controlled using shipboard ADCP cruise data. The temperature sensor of the C-T instruments is put in contact with a bag of ice before deployment and after recovery to generate a spike in the data to be used for synchronization of their internal clocks; similarly, the ADCPs are rubbed gently to generate a spike in the data. VMCM data are processed using the WHOI UOP software package (Prada, 1992).

All C-T instruments, as well as the ADCPs and the VMCMs from the WHOTS-15 mooring, returned full records of high-quality data. Details on the meteorological measurements are available at http://uop.whoi.edu/currentprojects/WHOTS/whots.html.

In addition to the mooring data, CTD casts were conducted during the WHOTS-16 cruise, measuring pressure, temperature, conductivity, and dissolved oxygen. Twelve CTD casts were conducted during the WHOTS-16 cruise, from September 21st through 28th, 2019. CTD profile data were collected at Station 20 (in transit to the WHOTS mooring), Station 50 (near the WHOTS-15 buoy), and Station 52 (near the WHOTS-16 buoy). The cast at Station 20 was 1500 m deep, and three acoustic releases (two to be used in the WHOTS-16 mooring and one backup) were attached to the rosette frame for function testing. Five CTD yo-yo casts were conducted to obtain profiles for comparison with subsurface instruments on the WHOTS-16 mooring after deployment, and five yo-yo casts were conducted for comparison with the WHOTS-15 mooring before recovery. These casts were started about 0.25 nm from the buoys with varying drift during each cast and consisted of 5 up-down cycles between near the surface and 204 to 218 m. Water samples were taken from all casts; 3 to 4 samples for each of them. These samples were to be...
analyzed for salinity at UH and used to calibrate the CTD conductivity sensors. Station numbers were assigned following the convention used during HOT cruises (see Table 2.25).

Table 2-25: CTD stations occupied during the WHOTS-16 cruise.

<table>
<thead>
<tr>
<th>Station/cast</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Location (using NMEA data)</th>
<th>Maximum pressure (dbar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52 / 1</td>
<td>10/10/2019</td>
<td>16:38</td>
<td>22° 40.391´ N, 157° 58.744´ W</td>
<td>215</td>
</tr>
<tr>
<td>52 / 2</td>
<td>10/10/2019</td>
<td>19:55</td>
<td>22° 40.551´ N, 157° 58.679´ W</td>
<td>211</td>
</tr>
<tr>
<td>52 / 3</td>
<td>10/10/2019</td>
<td>23:58</td>
<td>22° 40.790´ N, 157° 58.635´ W</td>
<td>211</td>
</tr>
<tr>
<td>52 / 4</td>
<td>10/11/2019</td>
<td>04:05</td>
<td>22° 41.023´ N, 157° 58.256´ W</td>
<td>211</td>
</tr>
<tr>
<td>52 / 5</td>
<td>10/11/2019</td>
<td>07:55</td>
<td>22° 40.551´ N, 157° 58.323´ W</td>
<td>209</td>
</tr>
<tr>
<td>50 / 1</td>
<td>10/06/2019</td>
<td>16:10</td>
<td>22° 45.101´ N, 157° 55.049´ W</td>
<td>213</td>
</tr>
<tr>
<td>50 / 2</td>
<td>10/06/2019</td>
<td>20:03</td>
<td>22° 44.962´ N, 157° 54.839´ W</td>
<td>211</td>
</tr>
<tr>
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<td>10/07/2019</td>
<td>00:04</td>
<td>22° 45.136´ N, 157° 55.144´ W</td>
<td>218</td>
</tr>
<tr>
<td>50 / 4</td>
<td>10/07/2019</td>
<td>04:08</td>
<td>22° 45.209´ N, 157° 55.006´ W</td>
<td>211</td>
</tr>
<tr>
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<td>10/07/2019</td>
<td>07:56</td>
<td>22° 44.787´ N, 157° 55.066´ W</td>
<td>210</td>
</tr>
</tbody>
</table>
Figure 2.31: WHOTS-15 mooring diagram
3.0 CRUISE SUMMARIES

The cruise summaries presented here give an overview of the activities conducted during the 2019 HOT cruises. The official Chief Scientist's reports can be found on the HOT web page (hahana.soest.hawaii.edu/hot/cruises.html).

3.1 HOT-309

Chief Scientist: D. SADLER
R/V Kilo Moana
January 14-18, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted northward.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 50). A near bottom CTD cast was completed at Station Kaena.

Five net tows for the core HOT zooplankton collection were completed successfully; two during the day and three during the night. The gas array was deployed and recovered.

Due to strong winds (>35 knots), the CTD cast at Station 50 (WHOTS) was delayed until 1830. The CTD cast at Station Kaena was cancelled due to the delay at Station 50.

Hyperpro casts were completed at Station Kahe and Station ALOHA. Casts with a new Hyperpro system were performed directly after the regular Hyperpro unit to compare the two systems.

The ADCP, underway fluorometer, thermosalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

Atmospheric aerosol samples were collected using a kite. Six sampling sessions were completed.

Winds during the cruise were mostly light from the South for the first 3 days with speeds of 0-10 kts. Winds picked up to 35 knots on January 17 as a front approached and swung to the North. The seas were 2-6 ft. with a large ground swell that induced large tension variations during CTD casts.
3.2 HOT-310

Chief Scientist: T. M. CLEMENTE  
R/V Kilo Moana  
February 18-22, 2019

All operations were completed at Station Kahe. Upon arriving at Station ALOHA the Sediment Traps and the WireWalker were successfully deployed and drifted NW in direction. The Primary Production CTD cast was cancelled due to the 0.322 wire getting damaged on the drum. The 0.322 wire was re-terminated, and the deep cast was conducted successfully. During the deep cast, weather at Station ALOHA worsened unexpectedly. Operations at Station ALOHA were suspended by the Captain due to weather conditions outside operational limits. The weather conditions were 35-40kt winds from the ESE, and 12-15 ft seas.

Operations were delayed approximately 8 hours due to weather. During the weather delay, the ship conducted speed log calibrations. Science operations resumed with a CTD cast at ~ 1700 on February 19th, 2019 following a modified schedule.

The Gas array was successfully deployed on the morning of February 20th, but the primary production array deployment was cancelled due to weather predicted for the recovery. The weather continued to remain unpredictable throughout the cruise.

On February 21st, we successfully conducted the optics cast followed by the recovery of the Sediment Trap array and WireWalker. Following these recoveries we conducted a Hyperpro cast and a one-hour 200 m CTD yo-yo cast at Station 50. We then transited to the trap deployment site where the three McLane Deep Moored Sediment Traps were successfully deployed and the anchor position triangulated. After deployment was complete we headed south to Honolulu Harbor and Pier 35.

Due to unexpected weather conditions and CTD winch issues the schedule was amended as follows:

- S2C1 was cancelled due to wire being damaged in the winch drum, therefore needing re-termination.
- Deployment of the Primary Production array was cancelled because we did not receive water from S2C1 for incubation experiment.
- Operations were suspended after the first deep cast S2C2 due to unexpected inclement weather and did not resume until the weather calmed down.
- The 36-hr of continuous CTDs was not completed (only 28 hours were completed).
- One Hyperpro cast was cancelled.
- One daytime net tow was cancelled.
- Approximately 8 hours were lost due to weather.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts and eleven 1000 m CTD casts were conducted at Station ALOHA. One 200 m yo-yo CTD cast was completed near the WHOTS mooring (Station 52) with five cycles completed.
Five net tows for the core HOT zooplankton collection were completed successfully; two during the day, and two during the night. Three net tows for TI & GJ were completed successfully.

The ADCP, underway fluorometer, thermostalinograph, transmissometer, pCO₂ and the ship’s meteorological suite ran with a few glitches during the cruise. The ADCP WH-300 was lost for several hours, but temporarily repaired. The remote IMET lab had to be restarted twice. The data recording rates for the Fluorometer and Thermostalinograph experienced glitches and were fixed by rebooting the IMET remote. We arrived at Pier 35 for off-loading on February 22nd, at 0820 (HST).

3.3 HOT-311

Chief Scientist: F. SANTIAGO-MANDUJANO
R/V Kilo Moana
May 1-5, 2019

Operations during the cruise were conducted without any major problems.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts and thirteen 1000 m CTD casts were conducted at Station ALOHA. One 200 m yo-yo CTD cast was completed near the WHOTS mooring (Station 50) with five cycles completed, and one near-bottom cast was conducted at Station Kaena (Station 6). The fluorometer displayed bad data during some of the CTD casts, apparently due to a faulty cable.

The ship’s Dynacon CTD winch with .322 wire were used for CTD deployments using the A-frame. Maximum CTD lowering speed was 50 m/min. Low CTD speeds (~30 m/s) were needed during the first ~200 m of downcasts, to prevent large tension fluctuations and slack in the CTD wire.

The Sediment Traps, Wirewalker, Primary Production and Gas Arrays were all deployed and recovered successfully.

Six net tows were completed successfully; three during the day, and three during the night.

The optical package was deployed as scheduled. The hyperpro casts were conducted as scheduled.

The thermostalinograph, fluorometer, SeaFlow, inline C-Star Transmissometer, and the IFCB were collecting data during the cruise.

The ADCP systems (OS38 narrow band, and WH300), were working during the cruise. The OS38 broad band was turned off during the cruise, as OTG was troubleshooting an apparent problem with the system.

The ship’s meteorological suite ran without interruption during the cruise.
Winds were easterlies about 20 kt early in the cruise, decreasing to 10-15 kt and turning southeasterlies for the rest of the cruise. Seas were about 4-5 feet. Strong winds and rain were present in the morning of May 4th during the passing of a weather front. A strong northwestward current (~ 1 kt) in the upper 100 m was persistent during the cruise. The sediment traps and other arrays drifted nearly 20 nm northwest from ALOHA Station.

3.4 HOT-312

Chief Scientist: D. SADLER
R/V Kilo Moana
June 10-14, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted southward.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 50). A near bottom CTD cast was completed at Station Kaena.

Five net tows for the core HOT zooplankton collection were completed successfully; Two during the day and three during the night. The gas array was deployed and recovered.

Hyperpro casts were completed at Station Kahe and Station ALOHA. Casts with a new Hyperpro system were performed directly after the regular Hyperpro unit to compare the two systems.

The ADCP, underway fluorometer, thermostalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

Aerial drone operations were conducted on all four days.

One ARGO float was deployed on June 13th on departure from Station ALOHA.

Winds during the cruise were mostly light from the South 5-10 kts. Seas were 2-6 ft.

Operations were slowed during the S2C1 CTD cast when a strand of the 0.322 wire broke and created a “birdcage” in the winch tensioning device. Once cleared, about 200 m were removed and the cable was re-terminated. The wire was visually inspected below 3000 m and rinsed during the upcast. The wire was deemed suitable to continue deep ctd casts. The wire condition was discussed in the post-cruise meeting and it was agreed that it would be lubricated on the next KM cruise.
3.5 HOT-313

Chief Scientist: D. SADLER
R/V Kilo Moana
June 30-July 4, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted northwestward.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, eleven 1000 m CTD casts, one 500m CTD cast, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 50). A near bottom CTD cast was completed at Station Kaena.

Five net tows for the core HOT zooplankton collection were completed successfully; two during the day and three during the night. The gas array was deployed and recovered.

Hyperpro casts were completed at Station Kahe and Station ALOHA. Casts with a new Hyperpro system were performed directly after the regular Hyperpro unit to compare the two systems.

The ADCP, underway fluorometer, thermosalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

Aerial drone operations were conducted on all four days.

One ARGO float was deployed on July 3rd on departure from Station ALOHA.

Winds during the cruise were from the South at 5-15 kts. Seas were 2-6 ft.

The Dynacon 0.322 winch exhibited level wind problems during the first 2 CTD casts. Adjustments were made but the issue persisted on the S2C2 deep cast. The cast was aborted at 500m and CTD operations were switched to the 0.681 wire. To overcome the 3 hour delay, one open CTD cast was dropped from the schedule. We were able to collect the missed water samples on other cast so that all samples were collected.

A design engineer from Hawbolt Industries observed the current CTD operations and equipment to assist in designing the new CTD winch/crane deployment system.
3.6 HOT-314

Chief Scientist: T. M. CLEMENTE
R/V Kilo Moana
August 1-5, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted northwestward.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 50). A near bottom CTD cast at Station Kaena was not completed due to delays in the ROV Lu’ukai elevator deployment.

Five net tows for the core HOT zooplankton collection were completed successfully; Two during the day and three during the night. The gas array was deployed and recovered.

Hyperpro casts were completed at Station Kahe and Station ALOHA.

Four, one hour Video Plankton Recorder (VPR) deployments and four, one hour Acoustic Zooplankton Fish Profiler (AZFP) deployments were conducted successfully throughout the cruise.

Aerial drone operations were conducted on three of the four days. Drone operations were cancelled on August 2nd, due to high winds (20-25kts).

The ADCP, underway fluorometer, thermostalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

The deployment of the elevator to assist with the future recovery of the ROV Lu’ukai was conducted using the 0.681 wire, however this attempt was unsuccessful after the weight broke free causing the elevator to return to the surface. The elevator was promptly recovered and then successfully re-deployed via free fall approximately about 200m to the ENE of the ROV Lu’ukai.

Winds at the beginning of the cruise were from the NE at 20-25kts and clocked around to the ESE lightening to 5-15kts throughout the cruise. Seas were 2-6 ft.

The Dynacon 0.322 winch exhibited level wind sensor problems during the first CTD casts. CTD operations were switched to the 0.681 wire for the remainder of the cruise. We were able to collect all water samples.
3.7 HOT-315

Chief Scientist: T. M. CLEMENTE  
R/V Kilo Moana  
September 3-7, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted Southwest.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 50). A near bottom CTD cast was completed at Station Kaena.

Six net tows for the core HOT zooplankton collection were completed successfully; Three during the day and three during the night. The gas array was deployed and recovered.

Hyperpro casts were completed at Station Kahe and Station ALOHA.

The ADCP, underway fluorometer, thermosalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

Winds at the beginning of the cruise were from the SSW at 5-10kts and clocked around to the NE strengthening to 15-20kts throughout the cruise. The currents were heading to the SW and the Seas were 2-6 ft.
3.8 HOT-316

Chief Scientist: D. SADLER
R/V Oceanus
October 16-20, 2019

All operations were completed at Station Kahe. Upon arrival at Station ALOHA, the WireWalker, Sediment Traps and Primary Production array were deployed and drifted north.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, eleven 1000 m CTD casts, and one 200m CTD cast were conducted at Station ALOHA. One 5 cycle yoyo CTD cast to 200 m was completed near the WHOTS mooring (Station 52). A near bottom CTD cast was completed at Station Kaena.

Four net tows for the core HOT zooplankton collection were completed successfully; Two during the day and two during the night. The gas array was deployed and recovered.

Hyperpro casts were completed at Station Kahe and Station ALOHA. The first Hyperpro cast at Station ALOHA was moved from October 17th to October 18th due to the revised schedule.

The ADCP, underway fluorometer, thermostalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

The large diameter of the HOT rosette caused tight clearances while deploying from the side squirt boom. One Bullister bottle was lost and several others were pushed downward during deployment of S2C2 while bringing the package to the surface from 10m. The wire angle tended under the ship causing contact with the CTD/rosette. The cast continued and the bottle was replaced after the cast. After the cast, a meeting with the captain produced revised deployment guidelines to prevent further contact. The time spent replacing the bottle and repositioning the other bottles was regained by cancelling one 1000m CTD open cast.

Wire tension was closely monitored during all CTD casts to ensure compliance with UNOLS Appendix A safety requirements. The first deep cast, S2C2 was terminated 30 m from the bottom to remain within the operating envelope. The second deep cast, S2C15, saw lower tensions due to less swell induced wire loading than the first deep cast and successfully reached maximum cast depth.

The O\textsuperscript{18} Primary Production experiment was cancelled due to rough sampling conditions.

Seaglider SG512 was deployed near Station ALOHA. The LADCP recorded data during all the casts, except during the first deep cast.

Winds during the cruise were from the South at 15-20 kts. Seas were 6-8 ft.
All operations were completed at Station Kahe. Upon arrival to Station ALOHA we accessed the weather forecast and decided to cancel the deployment of the WireWalker and the Sediment Trap array due to the predicted high winds (>30 knots) on the recovery day of December 21st.

One 1000 m CTD cast was completed at Station Kahe. One near bottom CTD casts and seven 1000 m CTD casts were conducted at Station ALOHA.

Four net tows for the core HOT zooplankton collection were completed successfully; two during the day and two during the night. In addition, 4 hand net tows (50 um mesh net) were collected for the ancillary group from Stanford.

Hyperpro casts were completed at Station Kahe and Station ALOHA. Casts with a newly calibrated Hyperpro system were performed directly after the regular Hyperpro unit to compare the two systems. One yo-yo and one profile was done on each.

The primary production cast was deployed and successfully recovered on December 19th. It was incubated for nearly 14 hours.

The ADCP, underway fluorometer, thermosalinograph, transmissometer and the ship’s meteorological suite ran without interruption during the cruise.

Winds at the beginning of the cruise were from the E at about 15kts and by Friday morning at 0200 the winds were over 30 knots from the NE with swells of 15 ft.

The Dynacon 0.322 winch exhibited level wind sensor problems during the first CTD casts on its way up, the crew managed to fix it and was working for the other casts. However a bad wrapping developed on the drum at about 4000 m during the deep cast, which remained on the drum for the rest of the casts.

The lowered-ADCP gave problems during data downloading, breaking the data into multiple files which had to be downloaded at the end of the CTD work instead of doing it after every cast.
4.0 RESULTS

4.1 Hydrography

4.1.1 2019 CTD Profiling Data

Profiles of temperature, salinity, oxygen, and potential density (\(\sigma_\theta\)) were obtained from data collected at Stations Kahe, ALOHA, WHOTS, and Kaena. The downcast CTD profiles from Station ALOHA during 2019 are presented in Figures 6.1.1a to i, together with the results of bottle determinations of oxygen and salinity. Stack plots of CTD temperature and salinity profiles for all 1000 m casts conducted at Station ALOHA are also presented (Figures 6.1.2a to i). The offset between bottle salinities and CTD profiles apparent in some of the cruise's salinity vs. pressure plots is due to the mismatch between the downcast CTD profile and the bottle salinities taken during the upcast. This salinity mismatch is caused mostly by vertical displacements of the density structure and disappears when plotted against potential temperature (lower right panel in Figures 6.1.1a to i). In some instances, mismatches are caused by the freshening of the surface water due to rain during the cast.

Profiles of chloropigment (in vivo fluorescence) are shown in Figures 6.1.3a to i. Chloropigment profiles show the chlorophyll maximum at the base of the euphotic zone, characteristic of the central North Pacific Ocean. Chloropigment profiles show the influence of internal waves when plotted against pressure, but remain relatively constant within a cruise when plotted against potential density (\(\sigma_\theta\)). However, there is substantial cruise-to-cruise variability in both the position and magnitude of the chlorophyll maximum.

Profiles of the data collected for Stations Kahe and Kaena during 2019 are presented in Figures 6.1.4a to i.

The potential temperature, salinity, and oxygen profiles obtained from the deep casts at Station ALOHA during 2019 are presented in Figures 6.1.5 through 7.

4.1.2 Time-series Hydrography, 1988-2019

The hydrographic data collected during the first thirty-one years of HOT are presented in a series of contour plots (Figures 6.1.8 through 23). These figures show the data collected in 2019 within the context of the longer time series. The CTD data used in these plots are obtained by averaging the data collected during the 36-hour period of burst sampling. Therefore, much of the variability, which would otherwise be introduced by internal tides, has been removed. Figures 6.1.8 and 6.1.9 show the contoured time-series for potential temperature and density (\(\sigma_\theta\)) in the upper 1000 dbar for all HOT cruises through 2019. Seasonal variation in temperature for the upper ocean is apparent in the maximum of the near-surface temperature of about 26 °C and a minimum of approximately 23 °C. Oscillations in the depth of the 5 °C isotherm below 500 dbar appear to be relatively large with displacements up to 100 dbar. The main pycnocline is observed between 100 and 600 dbar, with a seasonal pycnocline developing between June and December in the 50-100 dbar range (Figure 6.1.9). The cruise-to-cruise changes between February and July 1989 in the upper pycnocline illustrate that our quasi-monthly sampling does not always resolve variability in density.
Figures 6.1.10 through 13 show the contoured time-series record for salinity in the upper 1000 dbar for all HOT cruises through 2019. The plots show both the CTD and bottle results plotted against pressure and potential density. Most of the differences between the contoured sections of bottle salinity and CTD salinity are due to the coarse distribution of bottle data in the vertical as compared to the CTD observations. Some of the bottles in Figure 6.1.13 are plotted at density values lower than the indicated sea surface density. This is due to surface density changing from cast to cast within each cruise and even between the downcast and the upcast during a single cast.


The salinity maximum is generally found between 50 and 150 dbar and within 24-25 σθ. A salinity maximum region extends to the sea surface in the later part of 1990, 1993 and during 1998 throughout the early months of 2002, during late 2002 and early 2003, and again in the late part of 2003, early 2004, late 2004, early 2006, late 2008, early and late 2009, early to mid-2010, and early 2011, 2012, 2013, 2014 and 2015, as indicated by the 35.2 contour reaching the surface. The maximum shows salinities lower than usual in early 1995 and 1996, and throughout these two years, the values are below 35.2. During 1997 the salinities decreased even further, with values below 35.1, to recover rapidly after February 1998 to values prior to 1995. The increase continued throughout 2004, reaching record values of up to 35.45 in the first half of 1999. During 2005 and 2006, the salinities decreased to values comparable to those during 1998, and even further during 2007, to increase again in 2008, and to continue increasing to values above 35.3 throughout 2015. In 2016 the salinities started decreasing, reaching values below 35.2 during 2017, 2018 and decreasing even further during 2019. These salinity anomalies seem to be related to rainfall anomalies in the central North Pacific dominated by the El Niño/Southern Oscillation phenomenon and by the Pacific Decadal Oscillation (Lukas, 2001). During 1998 through 2004 period of high salinities in the salinity maximum, brief periods of relatively lower salinity were observed during the second half of 1998, 1999, and 2003.

The maximum value of salinity in the salinity maximum region is subject to short-term variations of about 0.1, which is probably due to the proximity of Station ALOHA to the region where this water is formed at the sea surface (Tsuchiya, 1968). The variability of this feature is itself variable. Throughout 1989 there were extreme variations of a couple of months duration with 0.2 amplitude. The variability was much smaller and slower thereafter, except for a few months of rapid variation in earlier 1992.

In the thermocline region below the salinity maximum (between 150 and 300 dbar), the salinities present a decreasing trend starting around 1995 until mid-2008, when it started increasing until mid-2010 and decreasing again until 2012.
The salinity minimum is found between 400 and 600 dbar (26.35-26.85 \(\sigma_0\)). There is no apparent seasonal variation in this feature, but there are distinct periods of higher-than-normal minimum salinity in early 1989, in the fall of 1990, in early 1992 in the summer of 1996, in the fall of 2006, late in 2007, fall 2008 and 2009, the second half of 2010, in the summer of 2011 and 2012 and during 2013. These variations are related to the episodic appearance at Station ALOHA of energetic fine structure and submesoscale water mass anomalies (Lukas and Chiswell, 1991; Kennan and Lukas, 1995). The anomalous high salinity centered at 400 dbar in early 2001 was apparently caused by the passing of an eddy during HOT-122 (Lukas and Santiago-Mandujano, 2001). This caused anomalous values in all the hydrographic variables observed at the ALOHA station. A similar feature centered at 350 dbar was observed in mid-2012 during HOT-241, however its anomalous values were not as extreme as during HOT-122.

Figures 6.1.14 and 6.1.15 show contoured time-series data for oxygen in the upper 1000 dbar at Station ALOHA. The oxygen data show a strong oxycline between 400 and 625 dbar (26.25-27.0 \(\sigma_0\)), and an oxygen minimum centered near 800 dbar (27.2 \(\sigma_0\)). Recurrent drops in the oxygen concentration can be seen throughout the time series between 25 and 26.25 \(\sigma_0\). These features are accompanied by a decrease in salinity and an increase in the nutrient concentration (see discussion below). The anomalous low oxygen centered at 400 dbar in early 2001 is due to the previously mentioned eddy feature observed during HOT-122. A similar low oxygen feature mentioned earlier is centered at 350 dbar in May 2012 (HOT-241).

The oxygen minimum exhibits some interannual variability, with values less than 30 \(\mu\text{mol kg}^{-1}\) frequently appearing during the time series. This variability can be seen in a plot of the mean oxygen in the intermediate waters spanning the oxygen minimum (27-27.8 \(\sigma_0\), Figure 6.1.24). Superimposed on this variability is a general trend towards lower oxygen values from 1989 through 1996, with an increase between 1997 and 2000, followed by a sharp decrease during 2001, and reaching record low values during the second half of 2002, and increasing sharply during 2003 and 2004 to reach high values in mid-2004, decreasing again to values close to those in 2002 by the end of 2005 and in the Fall of 2007. An increase that started in late 2005 reached high values in mid-2010, followed by a decrease throughout late 2012 and then by a sharp increase to record values in 2014 and a decrease from 2015 through 2018.

The surface layer shows seasonality in oxygen concentrations, with the highest values in the winter. This pattern corresponds roughly to the minimum in surface layer temperature (Figure 6.1.8).

Figures 6.1.16-23 show [nitrate + nitrite], SRP, and silica at Station ALOHA plotted against both pressure and potential density. The nitricline is located between about 200 and 600 dbar (25.75-27 \(\sigma_0\); Figures 6.1.16-17). Most of the variations seen in these data are associated with vertical displacements of the density structure, and when [nitrate + nitrite] is plotted versus potential density, most of the contours are level. Recurrent events with increasing [nitrate + nitrite] can be seen throughout the series between 25-26.25 \(\sigma_0\) (Figure 6.1.17). These events are accompanied by a decrease in the oxygen concentration mentioned above (Figure 6.1.15). The most obvious events occurred in March-April 1990, January 1992, May 1992, February-March 1995, early 1996, mid-to late 1997, July-September 1999, mid-2002, late-2003, late-2007, mid-2008, late-2012, mid-2013, late 2014 to early 2015, and mid to late 2017. These events can likely be attributed to mesoscale features such as eddies. It is possible for eddies to transport water with
different biogeochemical characteristics from distant sources into the region of Station ALOHA (Nolan, 2008). The SRP variability is similar to the [nitrate + nitrite] in the upper water column (Figure 6.1.20-21).

During 1996, the intermediate waters between 27.0-27.8 σθ recovered from anomalously low [nitrate + nitrite] observed during 1995 (Figure 6.1.18). This anomaly is apparent in a time series of mean [nitrate + nitrite] between 27.0-27.8 σθ (Figure 6.1.24). A decrease in [nitrate + nitrite] began in late 1994, with a comparable increase from mid-1995 through early 1996. The maximum decrease appears to be about 1 µmol kg⁻¹ below 27.5 σθ where nitrate concentrations are about 40 µmol kg⁻¹. This decrease appears to be authentic as it does have coherence over time. A precision estimate of 0.3% has been made for [nitrate + nitrite] measurements involving the high concentration samples associated with intermediate water (Dore et al., 1995). This translates to a precision of roughly 0.12 µmol kg⁻¹ for samples with a concentration of 40 µmol kg⁻¹. Hence, the 1 µmol kg⁻¹ decrease seen during 1995 is well within the precision level for the concentrations observed. However, the amount of the decrease could be approaching the accuracy limits of [nitrate + nitrite] measurements. This low [nitrate + nitrite] episode is accompanied by an increase in oxygen concentration (Figure 6.1.24). A [nitrate + nitrite] decrease of similar magnitude was observed in 2013-2014, reaching record low levels by the end of 2014, with a corresponding increase in oxygen concentration, and followed by a sharp [nitrate + nitrite] increase and oxygen decrease from early 2015 through 2018.

Intermediate water SRP (between 27.0-27.8 σθ) reached low values in early 1997, after a decreasing trend established in early 1994 (Figure 6.1.19). A time series of mean SRP in this layer shows this trend clearly (Figure 6.1.24). The SRP maintained relatively low values throughout early 2001 when it increased sharply and maintained an increasing trend until 2005, starting a decreasing trend ending in 2010 to values similar to those observed during 1997-2001. A sharp decrease was seen in 2013, corresponding to the [nitrate + nitrite] decrease mentioned above, but increased to 2012 values during 2014 and continued increasing through 2018. Decreases in phosphate in the deeper waters could persist for long periods as the oceanic ecosystem associated with Station ALOHA has been hypothesized to be phosphorous limited in recent years (Karl, 1995). Oxygen concentrations between 27.0-27.8 σθ vary during phosphate decrease from early 1994 through 1997 (Figure 6.1.24) without any apparent correlation.

4.2 Thermosalinograph

Thermosalinograph measurements of near-surface temperature (NST) and near-surface salinity (NSS), as well as navigation for the 2019 HOT cruises, are presented in Figures 6.2.1a to i and Figures 6.2.2a to i. Thermosalinograph data recorded while on Station can be compromised by ship effects such as temperature changes in the water due to the ship's hull and engine temperatures. Salinity can also be influenced by the ship when on the station as the ship provides a potential source of contamination and disturbs the water being sampled. Additional problems with the thermosalinograph system during cruises were indicated in Section 2.2.2.2.

In general, cooler near-surface temperatures and, in most cases, saltier near-surface salinities were observed at Station ALOHA compared to the data recorded near Oahu.
4.3 Meteorology

The meteorological data collected at 4-hour intervals by HOT program scientists include atmospheric pressure, sea-surface temperature, and wet and dry bulb air temperature. These data are presented in Figures 6.3.1 to 6.3.3. As described by Winn et al. (1991), parameters show evidence of annual cycles, although the daily and weekly ranges are nearly as high as the annual range for some variables. Wind speed and direction are also collected on HOT cruises. These data are presented in Figures 6.3.4a to i.

Hourly atmospheric pressure, air temperature, sea surface temperature, and relative humidity measurements were also available from the WHOTS buoy. These data are also plotted in Figures 6.3.1 through 6.3.3.

The thermostalinograph temperatures obtained at Station ALOHA during cruises are also plotted with the sea-surface meteorological observations in Figure 6.3.1 (lower panel) and show good agreement with these measurements.

The wind vectors from the WHOTS buoy are plotted together with the ship wind observations in Figures 6.3.4a to i.

Meteorological observations taken at 5-minute intervals on board the R/V Kilo Moana (HOT-309 to HOT-315 and HOT-317) are included in Section 4.10 (Figures 6.10.5a to h).

4.4 ADCP Measurements

An overview of the shipboard ADCP data is given by the plots of velocity as a function of time and depth while on station (Figures 6.4.1) and velocity as a function of latitude and depth during transit to and from Station ALOHA and Station Kaena, combined (Figures 6.4.2). As in previous years, currents were highly variable from cruise to cruise and within each cruise.

4.5 Biogeochemistry

4.5.1 Dissolved Oxygen

A contour plot of dissolved oxygen concentration in the upper 200 dbar of the water column from 1988-2019 based on analyses of water samples collected at discrete depths is shown in Figure 6.5.1. Dissolved oxygen shows a seasonal maximum between 60 and 110 m depth that develops during the summer-fall. This maximum, presumably of biological origin, is typically eroded during the winter.
4.5.2 Dissolved Inorganic Carbon and Total Alkalinity

Time-series of mixed-layer total alkalinity and DIC from 1988-2019 are presented in Figure 6.5.2. A contour plot of dissolved inorganic carbon is shown in Figure 6.5.3 and a contour plot of total alkalinity is shown in Figure 6.5.4.

Mixed layer total alkalinity normalized to 35 ppt salinity averages approximately 2304 µeq kg\(^{-1}\). No obvious seasonal or interannual pattern is evident. This observation is consistent with the results of Weiss et al. (1982) who concluded that total alkalinity normalized to salinity remains constant in both the North and South Pacific subtropical gyres. In contrast to total alkalinity, the concentration of DIC varies seasonally and interannually. DIC in the mixed layer is highest in March and April and lowest in September and October. This oscillation results from winter mixing of DIC rich waters from below and biological drawdown of CO\(_2\) in the shallow summer mixed layers (Ishii, M. et al., 2001). Using this data, Dore et al. (2003) found a significant decrease in the strength of the CO\(_2\) sink between 1989 and 2001 due to changes in regional precipitation and evaporation patterns brought on by climate variability.

4.5.3 pH

The structure of pH in the upper water column closely resembles that of dissolved inorganic carbon (Figure 6.5.3). There appears to be a slight increase in pH during the winter months and gradually decreases after that. This is directly related to the drawdown of inorganic carbon in the water column during the spring and summer periods.

4.5.4 Inorganic Nutrients

Mixed layer nutrient concentrations at Station ALOHA are at or well below the detection limits of the autoanalyzer methods. Alternative high-sensitivity analytical techniques were used to measure the nanomolar levels of [nitrate + nitrite] and SRP in the upper water column.

The chemiluminescent method of Cox (1980) as modified for seawater by Garside (1982) was used to determine the [nitrate+nitrite] content of near surface (0-200 m interval) water samples. Figure 6.5.5 shows the profiles obtained from our low level [nitrate + nitrite] analyses at Station ALOHA during 2019. The upper 100 m is generally depleted in [nitrate + nitrite] (LLN) with values usually not exceeding 30 nmol kg\(^{-1}\). A contour plot of LLN from 0-100 dbar during the period 1989-2019 time period is shown in Figure 6.5.6.

Dissolved inorganic P (DIP) was analyzed using the MAGnesium Induced Co-precipitation (MAGIC) method (Karl and Tien 1992). MAGIC improves both the sensitivity (detection limit ~ 2 nM) and the precision of the low level SRP (LLP) determination in oligotrophic seawaters. Figure 6.5.7 presents LLP data from 2019. At depths shallower than 100 m, LLP is typically less than 150 nmol kg\(^{-1}\). A contour plot of LLP from 0-100 dbar during the period 1989-2019 is shown in Figure 6.5.8. Several trends are evident, including a general reduction in DIP concentrations from >90 nmol kg\(^{-1}\) in 1989-1990 to <30 nmol kg\(^{-1}\) in 2001. The 0-100 m DIP depth integrated inventory was reduced from a high of >10 mmol P m\(^{-2}\) to a low of <2.5 mmol P m\(^{-2}\); more recently, DIP inventories appear to have stabilized and increased.

4.5.5 Total Organic Carbon

A contour plot of total organic carbon (TOC) from 0 to 1000 dbar over the 2002-2017 time period is presented in Figure 6.5.9. TOC concentrations are typically about 65-75 µmol kg\(^{-1}\) at the surface and decrease to about 45 µmol kg\(^{-1}\) at 800 m.

4.5.6 Particulate Bioelements

4.5.6.1 Particulate Carbon, Nitrogen and Phosphorus

Particulate carbon (PC), nitrogen (PN) and phosphorus (PPO\(_4\)) concentrations in the surface ocean over the 31 years of the program are shown in Figures 6.5.10-6.5.15. PC ranges from about 1-3 µmol kg\(^{-1}\), PN from 0.1-0.6 µmol kg\(^{-1}\) and PPO\(_4\) from 5-25 nmol kg\(^{-1}\) in the upper 100 m of the water column. An annual cycle is suggested with the greatest particulate bioelement concentrations in summer/fall and the lowest in winter. Substantial interannual variability is also noted, especially for PPO\(_4\).

4.5.6.2 Particulate Biogenic Silica

Particulate biogenic silica (PSi) concentrations in the surface ocean over the last 23 years of the program are shown in Figure 6.5.16 and Figure 6.5.17. PSi typically ranges from < 5 to about 30 nmol kg\(^{-1}\) in the upper 100 m of the water column. During the summer months in 1998, 2000 and 2005, PSi increased dramatically in the upper 50 m of the water. This feature appears associated with a large bloom of diatoms, as evidenced from the sharp increases in fucoxanthin (Figure 6.5.20).
4.5.7 Pigments

4.5.7.1 Standard Fluorometric Method

A contour plot of chlorophyll \(a\) concentrations measured using standard fluorometric techniques from 0 to 200 dbar during 1988–2019 is shown in Figure 6.5.18. A chlorophyll maximum with concentrations up to about 0.3 mg m\(^{-3}\) is observed at approximately 110 m depth. The magnitude of this feature exhibits significant interannual variability, with a pronounced period of low chlorophyll concentration lasting from 1992-1998. Chlorophyll \(a\) concentrations at depths shallower than 50 m display an annual cycle with winter maxima and summer minima.

4.5.7.2 High Performance Liquid Chromatography

Contour plots of HPLC-determined pigment concentrations from 0 to 200 dbar during 1988–2018 are shown in Figures 6.5.19-6.5.21. The pigments have been segregated into three chromophore classes: chlorophylls (chlorophyll \(a\), chlorophyll \(b\), and chlorophyll \(c\); Figure 6.5.19), photosynthetic carotenoids (19’-butanoyloxyfucoxanthin, fucoxanthin, and 19’-hexanoyloxyfucoxanthin; Figure 6.5.20) and photo-protective carotenoids (diadinoxanthin, zeaxanthin, and \(\alpha/\beta\)-carotene; Figure 6.5.21).

Chlorophyll \(a\) includes contributions by monovinyl and divinyl chlorophyll \(a\) and serves as a proxy for phytoplankton community biomass. Chlorophyll \(b\) includes contributions by monovinyl and divinyl chlorophyll \(b\) and is primarily derived from Prochlorococcus spp. since chlorophyll \(b\)-containing eukaryotes (e.g., chlorophytes and prasinophytes) are relatively rare at Station ALOHA as evidenced by the low and variable concentrations of lutein (chlorophyte marker) and prasinoxanthin (prasinoxanthin marker) (data not shown). Chlorophyll \(c\) includes contributions by chlorophylls \(c_1+c_2+c_3\) and serves as a proxy for chromophyte microalgal biomass (e.g., haptophytes, pelagophytes and diatoms). Photosynthetic carotenoids are typically useful for distinguishing phytoplankton at the “Class” level and the dominant species found at Station ALOHA include 19’-butanoyloxyfucoxanthin (pelagophyte marker), fucoxanthin (diatom marker), and 19’-hexanoyloxyfucoxanthin (haptophyte marker). The photo-protective carotenoids, diadinoxanthin, zeaxanthin, and \(\alpha/\beta\)-carotene are respectively associated with chromophyte microalgae, cyanobacteria (e.g., Prochlorococcus, Synechococcus and Trichodesmium spp.), and all members of the phytoplankton community.

Pigment distributions display distinct temporal patterns at Station ALOHA, with highest pelagophyte abundances during the periods 1989-1991 and 1996-2002. For other key groups, such as the haptophytes and cyanobacteria, there appears to be a recent post-1996 enhancement in their biomass relative to the previous 7-year period of observation. Diatoms, on the other hand, display sharp increases during the summer months of certain years (e.g., 1998 and 2000). These interannual variations in phytoplankton populations are likely linked to climate forcing (e.g., ENSO and PDO) and are currently under investigation.
4.5.8 Adenosine 5'-triphosphate

The concentration of particulate ATP resembles those of the particulate bioelements, showing maximum concentrations near the surface and a decreasing profile with depth (Figure 6.5.22). Surface ocean ATP varies between years more than three-fold, with conspicuously high levels noted in 1994-1995.

4.6 Biogeochemical Rate Measurements

4.6.1 Primary Production

The depth-integrated (0-200 m) results of the $^{14}$C incubations and pigment determinations for samples collected from CTD casts in 2019 are presented in Table 4.1. Also included for each cruise is the incubation duration and the total incident irradiance (400-700 nm) measured on the deck of the ship during the incubation period. Integrated primary production rates measured over all 31 years of the program are shown in Figure 6.6.1. A contour plot is shown in Figure 6.6.2. Depth-integrated rates of primary production vary seasonally, with summer maxima and winter minima. Overall, primary production varies by approximately a factor of five, ranging from ~200 to 1000 mg C m$^{-2}$ d$^{-1}$. The mean ($\pm$ sd) depth integrated primary production for the entire 31 year data set is 533 $\pm$ 136 mg C m$^{-2}$ d$^{-1}$. Although this value is higher than historical measurements for the oceanic central gyres (Ryther 1969), it is consistent with more recent measurements (Martin et al., 1987; Laws et al., 1989; Knauer et al., 1990).

Table 4.1: Primary production and pigment summary integrated values (0-200 m)

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<th>HOT</th>
<th>Incident Irradiance (E m$^{-2}$ d$^{-1}$)</th>
<th>Pigments (mg m$^{-2}$)</th>
<th>Incubation Duration (hrs)</th>
<th>Light Assimilation Rates (mg C m$^{-2}$ d$^{-1}$)</th>
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4.6.2 Particle Flux

Particulate carbon (PC), nitrogen (PN), phosphorus (PPO₄) and silica (PSi) fluxes at 150 m are presented in Table 4.2 and Figure 6.6.3 for the 1988-2019 time period. All four fluxes show large month-to-month and interannual variations. The magnitudes of PC and PN fluxes vary by about a factor of five, while PPO₄ and PSi fluxes varies by about a factor of 20. These particle flux measurements are consistent in magnitude with those measured in the central North Pacific Ocean during the VERTEX program (Martin et al., 1987; Knauer et al., 1990). However, the HOT data set reveals interannual changes not documented by earlier studies.

<table>
<thead>
<tr>
<th>HOT</th>
<th>PC Flux (mg m⁻² d⁻¹)</th>
<th>PN Flux (mg m⁻² d⁻¹)</th>
<th>PPO₄ Flux (mg m⁻² d⁻¹)</th>
<th>PSi Flux (mg m⁻² d⁻¹)</th>
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4.7 Optical Measurements

4.7.1 Solar Irradiance

Incident irradiance (400-700 nm wavelength band) measured using a LICOR LI-1500 during the cruise is shown in Figures 6.7.1a-i (upper panel). Incident irradiance is dependent on cloud cover, so it can potentially vary greatly from cruise-to-cruise or even day-to-day. But in general, as would be expected, higher values are measured during the summer months (HOT-313) and lower values in the winter months (HOT-317). To help interpret the results, integrated incident irradiance measured during the Primary Production incubation period is included in Table 4.1.

4.7.2 Downwelling Irradiance and Upwelling Radiance

Photosynthetically available radiation (PAR) was measured using a Satlantic HyperPro. Figure 6.7.2 shows the time-series of the 1 % light level and $K_{PAR}$ during the 22 years we’ve been collecting in-situ PAR data. Both vary seasonally. The average 1 % light-level at Station ALOHA is 105.7 m while the average $K_{PAR}$ between 100 & 150m is 0.0438 m⁻¹.
4.7.3 Laser In-Situ Scattering and Transmissometry (LISST-100X)

To investigate variability of particle size at Station ALOHA we have examined changes in the volume concentration of particles (in µL/L) over time via laser diffraction. By this method, a laser beam illuminates an in situ sample volume containing particles and the particle volume distribution between 1.25-250 µm is determined by inversion of the volume scattering function (VSF) at small forward angles. Particle volume estimated via the LISST was grouped into size bins of roughly 1.25-2 µm, 2-20 µm, and 20-100 µm. Particles in the 1.25-2 µm size range (Figure 6.7.3, top panel) generally exhibit maxima at depths of 100-140 m at or near the depth of the deep chlorophyll maxima. Conversely, 2-20 µm particles are maximal in the upper water column, typically within the mixed layer (middle panel). Notably, within this size class particles with an equivalent spherical diameter of ~5 µm are the most significant contributors to particle volume. No persistent depth profile was apparent for particles in the 20-100 µm size class (bottom panel). These data are being used to map shifts in particle size over multiple temporal and spatial scales and relate findings to phytoplankton standing stocks and primary productivity.

4.8 Microbial Community Structure

Depth profiles of heterotrophic bacterial (actually non-pigmented picoplankton and archaea) and *Prochlorococcus* abundances for each cruise are presented in Figure 6.8.1. A contour plot is shown in Figure 6.8.2. At the surface, heterotrophic bacterial numbers (shown in blue) range from 4 to 7 × 10^5 cells ml^-1. In most cases bacterial numbers decrease with depth although there are some profiles where the numbers remain fairly constant with depth throughout the euphotic zone. *Prochlorococcus* cells (shown in red) are found at concentrations ranging from around 2 to 3 × 10^5 ml^-1 at the surface and usually decrease with depth but with a subsurface maximum between 50 and 125 m.

Depth profiles of *Synechococcus* and pigmented eukaryotes are presented in Figure 6.8.3. A contour plot is shown in Figure 6.8.4. At the surface, *Synechococcus* numbers (shown in blue) range from 1 to 5 × 10^3 ml^-1, and decrease with depth with a subsurface maxima between 50 and 100 m. The abundances of picoeukaryotes (shown in red) typically ranges from 1 to 3 × 10^3 ml^-1, and similar to *Synechococcus*, the eukaryote populations generally decline with depth, occasionally exhibiting a subsurface maximum.

4.9 Zooplankton Community Structure

Temporal variation in mesozooplankton biomass during 1994-2019 is presented in Figure 6.9.1. Both zooplankton dry weight biomass (upper panel) and wet weight biomass (lower panel) are plotted. On average, zooplankton dry weight biomass was 12% of zooplankton wet weight biomass during the day (shown in red) and 13% during the night (shown in blue). The difference in biomass between zooplankton collected during the night and zooplankton collected during the day at Station ALOHA was significant for both dry and wet weights, and was caused by the upward migration of deep-living zooplankton and micronekton after sunset.
4.10 WHOTS Mooring

An overview of the data obtained with the Microcats in the WHOTS-15 mooring is given by the hourly averaged plots of temperature, salinity, and calculated potential density ($\sigma_\theta$) as a function of time for each of the instruments (Figures 6.10.1a to s), as well as contour plots of these variables as a function of time and depth (Figure 6.10.1t).

An overview of the mooring’s ADCP data is given by the contour plots of zonal and meridional current velocity as a function of time and depth (Figure 6.10.2).

Data from the 10 and 30 m VMCMs are also shown in the plots of zonal and meridional current velocity as a function of time (Figure 6.10.3).

Data obtained with the CTD during the WHOTS-15 mooring recovery (WHOTS-16 cruise) are shown in plots of temperature, conductivity, salinity, and dissolved oxygen as a function of depth (Figures 6.10.4a to e).

Data obtained with the WHOTS buoy meteorological instruments during HOT cruises conducted on the R/V Kilo Moana (HOT-309 to -315, and then on HOT-317) are shown together with the ship’s meteorological observations taken at 5-minute intervals (Figures 6.10.5a to h). Figures (1) include the ship’s port and starboard anemometers wind speed and direction relative to the ship, and the absolute wind speed and direction (true) after correcting for ship’s speed and heading (Sperry Marine Digital Gyroscope), together with the buoy’s measurements from the two data loggers. Figures (2) include the ship and buoy’s measurements of short and longwave radiation (Section 2.3), the ship’s measurements of Photosynthetically Active Radiation (PAR, Biospherical Quantum Scalar Reference), air temperature, and humidity. Figures (3) include ship’s and buoy’s measurements of barometric pressure and rain rate and accumulation.

The R/V Kilo Moana’s starboard anemometer had problems for all cruises, yielding to intermittent, constant wind direction values between 90° and 180° relative to the ship. The port anemometer functioned adequately. The RM Young and ORG precipitation gauges exhibited many glitches during all cruises. The shortwave radiation sensor worked very well for all cruises. The longwave radiation exhibited some offset during HOT-310, -311, and -317. The PAR functioned properly for all cruises, except during HOT-309, where negative values were observed. The RM Young RTD air temperature showed temperatures about 2°C lower than the humidity temperature sensor. The RTD sensor also displayed large glitches during HOT-313 and -314. The humidity temperature sensor functioned correctly during 2019, except for HOT-309, displaying some glitches in the dataset. The anemometer exhibited glitches during HOT-310 and -311.

The WHOTS-15 buoy logged data during cruises HOT-309 through -305 in data loggers #19 and #42. The data logger #19 did not record precipitation data during 2019. Both loggers displayed lower humidity temperature values compared to the KM data. The data logger #19 displayed some gaps during HOT-309.

The WHOTS-16 buoy logged data during HOT-317 in data loggers #7 and #8. The first logger did not record humidity, temperature and precipitation during HOT-317. The data logger #8 did not record wind data during HOT-317.
5.0 REFERENCES


6.0 FIGURES

6.1 Hydrography

Figure 6.1.1a-i: [Upper left panel] Temperature, salinity, oxygen and potential density ($\sigma_0$) as a function of pressure for the WOCE deep cast at Station ALOHA for each HOT cruise. [Upper right panel] Plot of [nitrate + nitrite], soluble reactive phosphorus, silicate, and bottle dissolved oxygen as a function of potential temperature for all water samples. [Lower left panel] CTD temperature and salinity plotted as a function of pressure to 1000 dbar for all casts at ALOHA. [Lower right panel] Salinity and oxygen from CTD and water samples plotted as a function of potential temperature. Only the CTD oxygen traces in which bottle oxygen samples were taken are included.

Figure 6.1.2a-i: [1st panel] Stack plots of temperature versus pressure to 1000 dbar at Station ALOHA. Offset is 2 °C. [2nd panel] Stack plots of salinity versus pressure to 1000 dbar at Station ALOHA. The offset is 0.1.

Figure 6.1.3a-i: Stack plots of CTD chloropigment (fluorescence) and bottle fluorometric chlorophylls+pheopigments versus pressure to 200 dbar [1st panel] and versus to 25.5 kg/m$^3$ [2nd panel] at Station ALOHA. Chloropigment values have been offset by 0.2 μg/l for both plots.

Figure 6.1.4a-i: [Upper left panel] Temperature, salinity, oxygen and potential density ($\sigma_0$) as a function of pressure for the cast at Station Kahe for each HOT cruise in which the station was occupied. [Upper right panel] Plot of CTD and bottle dissolved oxygen and salinity as a function of potential temperature for water samples at Station Kahe. [Lower left panel] Plot of temperature, salinity, oxygen, and $\sigma_0$ as a function of pressure at Station Kaena for each HOT cruise in which the station was occupied. [Lower right panel] Plot of CTD and bottle salinity and oxygen as a function of potential temperature at Station Kaena.

Figure 6.1.5: [Upper panel] Potential temperature versus pressure for all deep casts in 2019. [Lower panel]: Potential temperature versus pressure deeper than 2500 dbar for all deep casts in 2019.

Figure 6.1.6: [Upper panel] Salinity versus potential temperature for all deep casts in 2019. [Lower panel]: Salinity versus potential temperature for all deep casts in 2019 in the 1-5 °C range.

Figure 6.1.7: [Upper panel] Oxygen concentrations from calibrated oxygen sensor data versus potential temperature for all deep casts in 2019. [Lower panel] Oxygen versus potential temperature for all deep casts in 2019 in the 1-5 °C range.

Figure 6.1.8: Contour plot of CTD potential temperature versus pressure for HOT cruises 1-317.

Figure 6.1.9: Contour plot of $\sigma_0$, calculated from CTD pressure, temperature and salinity, versus pressure for HOT cruises 1-317.

Figure 6.1.10: Contour plot of CTD salinity versus pressure for HOT cruises 1-317.
Figure 6.1.11: Contour plot of CTD salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.12: Contour plot of bottle salinity versus pressure for HOT cruises 1-317. The solid circles indicate location of samples in the water column.

Figure 6.1.13: Contour plot of bottle salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.14: Contour plot of bottle oxygen versus pressure for HOT cruises 1-317. The solid circles indicate location of samples in the water column.

Figure 6.1.15: Contour plot of bottle oxygen versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.16: Contour plot of [nitrate + nitrite] versus pressure for HOT cruises 1-317. The solid circles indicate location of samples in the water column.

Figure 6.1.17: Contour plot of [nitrate + nitrite] versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.18: Contour plot of [nitrate + nitrite] versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-317.

Figure 6.1.19: Contour plot of soluble reactive phosphorus versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-317.

Figure 6.1.20: Contour plot of soluble reactive phosphorus versus pressure for HOT cruises 1-317. The solid circles indicate location of samples in the water column.

Figure 6.1.21: Contour plot of soluble reactive phosphorus versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface

Figure 6.1.22: Contour plot of silicate versus pressure for HOT cruises 1-317. The solid circles indicate location of samples in the water column.

Figure 6.1.23: Contour plot of silicate versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-317. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.24: Time series of mean bottle dissolved oxygen for HOT cruises 1-317 (upper panel), [nitrate + nitrite] (middle panel) and soluble reactive phosphorus (lower panel) between 27.0 and 27.8 $\sigma_0$ isopycnals. The smooth line is the spline fit to the data. The asterisks indicate the annual mean.
6.2 Thermosalinograph

Figure 6.2.1a-i: Thermosalinograph data for HOT-309 through-317 cruises in 2019. Continuous near-surface temperature, salinity and $\sigma$ (continuous lines), CTD data at a depth of the thermosalinograph water intake (circles), and salinity bottle data (crosses). The section between the vertical dashed lines indicates the period when Station ALOHA was occupied.

Figure 6.2.2a-i: Navigation data during HOT-309 through -317 cruises in 2019: latitude, longitude, and ship speed. The section between the vertical dashed lines indicates the period when Station ALOHA was occupied.

6.3 Meteorology

Figure 6.3.1: [Upper panel] Atmospheric pressure while at Station ALOHA for 2019 HOT cruises (open circles), and WHOTS buoy hourly measurements throughout the year (continuous line). [Lower panel] Sea surface temperature measured from a bucket sample while at Station ALOHA for 2019 HOT cruises (open circles), WHOTS buoy hourly measurements throughout the year (continuous thin line), and near-surface temperatures from the thermosalinograph while at Station ALOHA during HOT cruises (thick line).

Figure 6.3.2: [Upper panel] Dry bulb air temperature while at Station ALOHA for 2019 HOT cruises (open circles), and WHOTS buoy hourly measurements throughout the year (continuous line). [Lower panel] Wet bulb air temperature while at Station ALOHA for 2019 HOT cruises.

Figure 6.3.3: [Upper panel] Sea surface temperature minus dry air temperature while at Station ALOHA for 2019 HOT cruises (open circles), and WHOTS buoy hourly measurements throughout the year (continuous line). [Lower panel] Relative humidity at Station ALOHA for 2019 HOT cruises and WHOTS buoy hourly measurements throughout the year (continuous line).

Figures 6.3.4a to i: [Upper panel] True winds measured at Station ALOHA for 2019 HOT cruises. [Middle panel] Continuous true wind record from the ship’s anemometer during HOT cruises. [Lower panel] True winds measured by WHOTS buoy. The orientation of the arrows indicates the wind direction; up is northward, right is eastward.

6.4 ADCP Measurements

Figures 6.4.1a-i: Velocity fields at Station ALOHA were obtained during 2019 cruises conducted on the R/V Kilo Moana and Oceanus (Section 2.4). Top panels show hourly averages while the ship was on station. The orientation of each stick gives the direction of the current: up is northward, and to the right is eastward. Bottom panels show the results of a least-squares fit of hourly averages to a mean, trend, semi-diurnal and diurnal tides; the on-station time-series were not long enough to fit an inertial cycle. In the first column, the arrow shows the mean current and the headless stick shows the sum of the mean plus the trend at the end of the station. For each harmonic, the current ellipse is shown in the first column. The
orientation of the stick in the second column shows the direction of the harmonic component of the current at the beginning of the station and the arrowhead at the end of the stick shows the direction of rotation of the current vector around the ellipse. Some of the station data gaps are due to excursions to retrieve the primary productivity array and floating sediment traps.

Figures 6.4.2a-i: Velocity fields on the transits to and from Station ALOHA and Station Kaena. The orientation of each stick gives the direction of the current: up is northward, and to the right is eastward. Velocity is shown as a function of latitude averaged in 10-minute intervals.

6.5 Biogeochemistry

Figure 6.5.1: Contour plot of bottle dissolved oxygen versus pressure for HOT cruises 1-317 from 0-200 dbar. Solid dots indicate water column sample locations.

Figure 6.5.2: [Upper panel] Time series of mean mixed layer total alkalinity (normalized to 35 ppt salinity) for HOT cruises 1-317. [Lower panel] Mixed layer dissolved inorganic carbon (normalized to 35 ppt salinity) for HOT cruises 1-317. Error bars represent standard deviation of pooled samples collected between 0 and 45 dbar.

Figure 6.5.3: [Upper panel] Contour plot of dissolved inorganic carbon versus pressure for HOT cruises 1-317 from 0-200 dbar. Solid dots indicate water column sample locations. [Lower panel] Contour plot of dissolved inorganic carbon normalized to 35 ppt salinity.

Figure 6.5.4: [Upper panel] Contour plot of total alkalinity versus pressure for HOT cruises 1-317 from 0-200 dbar. Solid dots indicate water column sample locations. [Lower panel] Contour plot of total alkalinity normalized to 35 ppt salinity.

Figure 6.5.5: Depth profiles from 0-150 dbar of low-level [nitrate + nitrite] at Station ALOHA for 2019 HOT cruises by the high-sensitivity chemiluminescence method.

Figure 6.5.6: [Upper panel] Contour plot from 0-100 dbar of low-level [nitrate + nitrite] at Station ALOHA for HOT cruises 1-317. [Lower panel] 0-100 dbar integral of LLN at Station ALOHA for HOT cruises 1-317.

Figure 6.5.7: Depth profile from 0-250 dbar of low-level soluble reactive phosphorus at Station ALOHA for 2019 HOT cruises by the high-sensitivity magnesium induced coprecipitation (MAGIC) method.

Figure 6.5.8: [Upper panel] Contour plot from 0-100 dbar of low-level soluble reactive phosphorus at Station ALOHA for HOT cruises 1-317. [Lower panel] 0-100 dbar integral of LLP at Station ALOHA for HOT cruises 1-317.

Figure 6.5.9: Contour plot from 0-1000 dbar of total organic carbon at Station ALOHA for HOT cruises 134-295. Solid dots indicate water column sample locations.
**Figure 6.5.10:** [Upper panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-317 from 0-50 dbar. [Lower panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-317 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.11:** Contour plot from 0-350 dbar of particulate carbon at Station ALOHA for HOT cruises 1-317. Solid dots indicate water column sample locations.

**Figure 6.5.12:** [Upper panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-317 from 0-50 dbar. [Lower panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-317 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.13:** Contour plot from 0-350 dbar of particulate nitrogen at Station ALOHA for HOT cruises 1-317. Solid dots indicate water column sample locations.

**Figure 6.5.14:** [Upper panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-317 from 0-50 dbar. [Lower panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-317 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.15:** Contour plot from 0-350 dbar of particulate phosphorus at Station ALOHA for HOT cruises 1-317. Solid dots indicate water column sample locations.

**Figure 6.5.16:** [Upper panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-317 from 0-50 dbar. [Lower panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-317 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.17:** Contour plot from 0-200 dbar of particulate biogenic silica at Station ALOHA for HOT cruises 79-317. Solid dots indicate water column sample locations.

**Figure 6.5.18:** Contour plot from 0-200 dbar of fluorometric chlorophyll a concentrations at Station ALOHA for HOT cruises 2-317. Solid dots indicate water column sample locations.

**Figure 6.5.19:** Contour plots from 0-200 dbar of HPLC chlorophyll (chlorophyll a, chlorophyll b & chlorophyll c) concentrations at Station ALOHA for HOT cruises 1-308.

**Figure 6.5.20:** Contour plots from 0-200 dbar of HPLC photosynthetic carotenoid (19'-butanoyloxyfucoxanthin, fucoxanthin & 19'-hexanoyloxyfucoxanthin) concentrations at Station ALOHA for HOT cruises 1-308.

**Figure 6.5.21:** Contour plots from 0-200 dbar of HPLC photo-protective carotenoid (diadinoxanthin, zeaxanthin & α- plus β-carotene) concentrations at Station ALOHA for HOT cruises 1-308.
Figure 6.5.22: Contour plot from 0-350 dbar of particulate adenosine 5’-triphosphate concentrations at Station ALOHA for HOT cruises 1-317. Solid dots indicate water column sample locations.

### 6.6 Biogeochemical Rate Measurements

**Figure 6.6.1**: [Upper panel] Integrated (0-200 m) primary production rates from 1988-2019. Filled circles and crosses indicate *in situ* and on deck incubations, respectively. Solid line represents the average production (533 mg C m⁻² d⁻¹), dashed lines are ± one standard deviation (136 mg C m⁻² d⁻¹). [Lower panel] 3-point running mean of integrated primary production rates. Symbols same as in upper panel.

**Figure 6.6.2**: Contour plot from 0-100 m of primary production rates at Station ALOHA for HOT cruises 1-317. Solid dots indicate water column sample locations.

**Figure 6.6.3**: Particulate carbon flux [Top panel], Particulate nitrogen flux [2nd panel], Particulate phosphorus flux [3rd panel] and Particulate silica flux [Bottom panel] at 150 m measured on all HOT cruises from 1988-2019. Error bars represent the standard deviation of determinations from triplicate particle interceptor traps.

### 6.7 Optical Measurements

**Figure 6.7.1a–i**: [Upper panel] Incident irradiance (400-700 nm wavelength band) measured using a Li-COR LI-1500 data logger during each cruise. The red, blue & green lines represent the minimum, average & maximum light value respectively of 10-minute intervals. The total incident irradiance measured when the primary production array was out (represented by the light-blue shaded area) is also calculated and included at the top of each figure. [Lower left panel] Photosynthetically available radiation (PAR[z] : derived from \( K_{\text{PAR}} \) using the average downcast surface light) versus depth for every profile at Station ALOHA. [Lower right panel] PAR attenuation coefficient (\( K_{\text{PAR}} \)) versus depth for every profile at Station ALOHA.

**Figure 6.7.2**: [Upper panel] Depth of the 1% surface PAR light level for HOT cruises 90-317. The solid red line represents the average 1% surface PAR light depth (105.7 m) at Station ALOHA. [Lower panel] Mean PAR attenuation coefficient (\( K_{\text{PAR}} \)) for HOT cruises 90-317 from 100-150m. The solid red line represents the average \( K_{\text{PAR}} \) (0.0438 m⁻¹) at Station ALOHA.

**Figure 6.7.3**: Contour plot from 0-200 m of the number of particles measured by the Laser In-Situ Scattering and Transmissometry (LISST-100X) Sensor grouped into size bins of roughly 1.25-2 µm [Top panel], 2-20 µm [Middle panel], and 20-100 µm [Bottom panel]. Solid dots indicate water column sample locations.
6.8 Microbial Community Structure

**Figure 6.8.1**: Depth profiles (0-200 m) of Heterotrophic bacteria (blue) and *Prochlorococcus* numbers (red) measured by flow cytometry at Station ALOHA for 2019.

**Figure 6.8.2**: Contour plots from 0-200 dbar of Heterotrophic bacteria [Upper panel] and *Prochlorococcus* numbers [Lower panel] at Station ALOHA for HOT cruises 177-317. Solid dots indicate water column sample locations.

**Figure 6.8.3**: Depth profiles (0-200 m) of *Synechococcus* (blue) and Eukaryote numbers (red) measured by flow cytometry at Station ALOHA for 2019.

**Figure 6.8.4**: Contour plots from 0-200 dbar of *Synechococcus* [Upper panel] and Eukaryote numbers [Lower panel] at Station ALOHA for HOT cruises 23-317. Solid dots indicate water column sample locations.

6.9 Zooplankton Community Structure

**Figure 6.9.1**: Dry weight biomass [Upper panel] and wet weight biomass [Lower panel] of mesozooplankton collected at Station ALOHA for HOT cruises 51-317. Both nighttime (blue) and daytime (red) biomass are plotted.

6.10 WHOTS Mooring

**Figure 6.10.1.a**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 2 m on the WHOTS-15 mooring.

**Figure 6.10.1.b**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 7 m on the WHOTS-15 mooring.

**Figure 6.10.1.c**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 15 m on the WHOTS-15 mooring.

**Figure 6.10.1.d**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 25 m on the WHOTS-15 mooring.

**Figure 6.10.1.e**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 35 m on the WHOTS-15 mooring.

**Figure 6.10.1.f**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 40 m on the WHOTS-15 mooring.

**Figure 6.10.1.g**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 45 m on the WHOTS-15 mooring.
**Figure 6.10.1.h**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 50 m on the WHOTS-15 mooring.

**Figure 6.10.1.i**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 55 m on the WHOTS-15 mooring.

**Figure 6.10.1.j**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 65 m on the WHOTS-15 mooring.

**Figure 6.10.1.k**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 75 m on the WHOTS-15 mooring.

**Figure 6.10.1.l**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 85 m on the WHOTS-15 mooring.

**Figure 6.10.1.m**: Temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 95 m on the WHOTS-15 mooring.

**Figure 6.10.1.n**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 105 m on the WHOTS-15 mooring.

**Figure 6.10.1.o**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 120 m on the WHOTS-15 mooring.

**Figure 6.10.1.p**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 135 m on the WHOTS-15 mooring.

**Figure 6.10.1.q**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Microcat SBE-37 deployed at 155 m on the WHOTS-15 mooring.

**Figure 6.10.1.r**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Seacat SBE-16 deployed at 4714 m on the WHOTS-15 mooring.

**Figure 6.10.1.s**: Pressure, temperature, salinity, and potential density ($\sigma_\theta$) from Seacat SBE-16 deployed at 4714 m on the WHOTS-15 mooring.

**Figure 6.10.1.t**: Temperature, salinity and potential density ($\sigma_\theta$) contours as a function of depth and time from Microcat instruments in the WHOTS-15 mooring.

**Figure 6.10.2.a**: Zonal and meridional current velocity contours as a function of depth and time for the upward-looking ADCP deployed at 47.5 m in the WHOTS-15 mooring.

**Figure 6.10.2.b**: Zonal and meridional current velocity contours as a function of depth and time for the upward-looking ADCP deployed at 125 m in the WHOTS-15 mooring.

**Figure 6.10.3**: Zonal and meridional current velocity as a function of time for the VMCMs deployed at 10 and 30 m on the WHOTS-15 mooring.
Figure 6.10.4.a: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-16 cruise, CTD Station 50 casts 1 and 2.

Figure 6.10.4.b: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-16 cruise, CTD Station 50 casts 3 and 4.

Figure 6.10.4.c: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-16 cruise, CTD Station 50 cast 5 and Station 52 cast 1.

Figure 6.10.4.d: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-16 cruise, CTD Station 52 casts 2 and 3.

Figure 6.10.4.e: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-16 cruise, CTD Station 52 casts 4 and 5.

Figure 6.10.5.a.1: Time-series of wind speed [top panel] and direction [second panel] relative to the ship; ship speed and heading [third panel]; “true” wind speed [fourth panel] and direction [fifth panel] in Earth coordinates for the port (red) and starboard (blue) anemometers on the R/V Kilo Moana during the HOT-309 cruise. The fourth and fifth panels also include data from the WHOTS anemometers (circles). The vertical solid lines indicate the initial and final time when the station ALOHA was occupied.

Figure 6.10.5.a.2: Time-series of short wave radiation [top panel]; longwave radiation [second panel]; Photosynthetically Active Radiation [third panel]; air temperature from the Young RTD (red) and the Rotronic (blue) [fourth panel]; and humidity from instruments on the R/V Kilo Moana during the HOT-309 cruise. The top, second, fourth, and fifth panels also include data from the WHOTS buoy instruments (circles). The vertical solid lines indicate the initial and final time when the station ALOHA was occupied.

Figure 6.10.5.a.3: Time-series of barometric pressure [top panel]; rain rate [second panel] and rain accumulation [third panel] from the OSI Optical Rain Gauge; and precipitation rate from the RM Young [fourth panel] on the R/V Kilo Moana during the HOT-309 cruise. The plots also include data from the WHOTS buoy instruments (circles). The vertical solid lines indicate the initial and final time when the station ALOHA was occupied.

Figure 6.10.5.b.1: Same as in Figure 6.10.5.a.1, but for the HOT-310 cruise.

Figure 6.10.5.b.2: Same as in Figure 6.10.5.a.2, but for the HOT-310 cruise.

Figure 6.10.5.b.3: Same as in Figure 6.10.5.a.3, but for the HOT-310 cruise.

Figure 6.10.5.c.1: Same as in Figure 6.10.5.a.1, but for the HOT-311 cruise.

Figure 6.10.5.c.2: Same as in Figure 6.10.5.a.2, but for the HOT-311 cruise.

Figure 6.10.5.c.3: Same as in Figure 6.10.5.a.3, but for the HOT-311 cruise.

Figure 6.10.5.d.1: Same as in Figure 6.10.5.a.1, but for the HOT-312 cruise.
**Figure 6.10.5.d.2**: Same as in Figure 6.10.5.a.2, but for the HOT-312 cruise.

**Figure 6.10.5.d.3**: Same as in Figure 6.10.5.a.3, but for the HOT-312 cruise.

**Figure 6.10.5.e.1**: Same as in Figure 6.10.5.a.1, but for the HOT-313 cruise.

**Figure 6.10.5.e.2**: Same as in Figure 6.10.5.a.2, but for the HOT-313 cruise.

**Figure 6.10.5.e.3**: Same as in Figure 6.10.5.a.3, but for the HOT-313 cruise.

**Figure 6.10.5.f.1**: Same as in Figure 6.10.5.a.1, but for the HOT-314 cruise.

**Figure 6.10.5.f.2**: Same as in Figure 6.10.5.a.2, but for the HOT-314 cruise.

**Figure 6.10.5.f.3**: Same as in Figure 6.10.5.a.3, but for the HOT-314 cruise.

**Figure 6.10.5.g.1**: Same as in Figure 6.10.5.a.1, but for the HOT-315 cruise.

**Figure 6.10.5.g.2**: Same as in Figure 6.10.5.a.2, but for the HOT-315 cruise.

**Figure 6.10.5.g.3**: Same as in Figure 6.10.5.a.3, but for the HOT-315 cruise.

**Figure 6.10.5.h.1**: Same as in Figure 6.10.5.a.1, but for the HOT-317 cruise.

**Figure 6.10.5.h.2**: Same as in Figure 6.10.5.a.2, but for the HOT-317 cruise.

**Figure 6.10.5.h.3**: Same as in Figure 6.10.5.a.3, but for the HOT-317 cruise.
7.0 HOT PROGRAM PRESENTATIONS AND PUBLICATIONS

The following is a listing of Presentations & Publications as of May 2021. For an up-to-date listing please refer to our Web site (hahana.soest.hawaii.edu/hot/hotpub.html).

7.1 Invited Presentations and Published Abstracts


9. 1991 Lukas, R. Water mass variability observed in the Hawaii Ocean Time Series. EOS, Transactions of the American Geophysical Union 72, 70.


13. 1992 Anbar, A. D. Rhenium in seawater: Confirmation of generally conservative behavior. EOS, Transactions of the American Geophysical Union 73, 278.


36. 1994 Campbell, L., C. D. Winn, R. Letelier, D. Hebel and D. M. Karl. Temporal variability in phytoplankton fluorescence at Station ALOHA. EOS, Transactions of the American Geophysical Union 75, 100.


38. 1994 Lukas, R., F. Bingham and A. Mantyla. An anomalous cold event in the bottom water observed north of Oahu. EOS, Transactions of the American Geophysical Union 75, 205.


65. 1995 Yuan, J. Collecting iron samples from well mounted on CTD rosette. EOS, Transactions of the American Geophysical Union 76, S175.


136. 2004 Church, M. J. Dynamics of bacterioplankton growth and production in the oligotrophic North Pacific Ocean. Ocean Sciences Department, University of California Santa Cruz.


139. 2005 Church, M. J. Hawaii Ocean Time-series (HOT): A window to ecosystem variability in the subtropical North Pacific Ocean. International Cenuse of Marine Microbes (ICoMM), Honolulu, HI.

140. 2005 Church, M. J. Photoenhanced heterotrophic production in the North Pacific Ocean. ASLO Aquatic Sciences Meeting, Salt Lake City, Utah.


142. 2006 Church, M. J., C. Mahaffey, A. A. Fong, J. P. Zehr, D. M. Karl. Time series investigations into the dynamics of nitrogen fixing bacteria and rates of nitrogen fixation at Station ALOHA. ASLO/TOS/AGU Ocean Sciences Meeting, Honolulu, HI, February 2006.


D. M. Karl. Meridional variations in dissolved and particulate matter concentrations and stoichiometries in the tropical and subtropical Pacific Ocean. ASLO/TOS/AGU Ocean Sciences Meeting, Honolulu, HI, February 2006.


158. 2006 Church, M. J. Microbial Dynamics at Station ALOHA in the North Pacific Subtropical Gyre. Pioneering Studies of Young Scientists on Chemical Pollution and Environmental Changes. Ehime University, Matsuyama, Japan.

159. 2006 Church, M. J. Advances in understanding the time and space dynamics of marine microbes. Department of Oceanography, University of Hawaii, Honolulu, HI.

160. 2006 Church, M. J. Temporal and spatial dynamics of marine microbes. Monterey Bay Aquarium and Research Institute, Monterey, CA.

162. 2007 Church, M. J. Mesoscale forcing of microbial activity and biogeochemistry in the North Pacific Ocean. School of Oceanography, University of Washington.


164. 2007 Goebel, N. L., C. A. Edwards, M. J. Church, K. M. Achilles, J. P. Zehr. Relative contributions of three cyanobacteria phylotypes to total nitrogen (N$_2$) fixation at Station ALOHA. ASLO Aquatic Sciences Meeting, Santa Fe, New Mexico.


175. 2008 Church, M. J. Microbes and Climate: Stories from the Sea. Hanauma Bay Evening Lecture Series. Honolulu, HI.


196. 2011 Brzezinski, M. A., J. W. Krause, B. Li, M. J. Church. Interannual variability and drivers of the silicon cycle at the Hawaii Ocean Time-series Station ALOHA. Aquatic Sciences Meeting (S02), San Juan, Puerto Rico, February 2011.


profiling floats with chemical sensors. Aquatic Sciences Meeting (S02), San Juan, Puerto Rico, February 2011.

200. 2011 Lomas, M. W., M. J. Church. BATS and HOT: Comparative analysis of similar yet different marine ecosystems. Aquatic Sciences Meeting (S02), San Juan, Puerto Rico, February 2011.


203. 2012 Alford, M. H., R. Lukas, B. M. Howe, A. Pickering and F. Santiago-Mandujano. Moored observations of episodic abyssal flow and mixing at Station ALOHA. Ocean Sciences Meeting (090), Salt Lake City, UT, February 2012.


205. 2012 Dore, J. E., R. Lukas, M. J. Church, D. W. Sadler and D. M. Karl. Consistent trends and patterns of interannual variability in surface ocean CO₂ at contrasting sites windward and leeward of the Hawaiian islands. Ocean Sciences Meeting (039), Salt Lake City, UT, February 2012.


207. 2012 Howe, B. M., R. Lukas, F. Deunnebier. ALOHA Cabled Observatory: Early results including acoustics. Ocean Sciences Meeting (047), Salt Lake City, UT, February 2012.


232. 2014 Foley, J. M. *Taking time-series to the streets: educational programs that communicate Station ALOHA research*. Ocean Sciences Meeting (049), Honolulu, HI, February 2014.


266. 2017 Curless, S. E.; Church, M. J.; Segura-Noguera, M.; Karl, D. K. Ammonium concentrations at Station ALOHA - Improved methodology allows for full ocean depth analysis. ASLO Aquatic Sciences Meeting (040), Honolulu, HI, February-March 2017.


273. 2017 Gradoville, M. R.; Crump, B. C.; Letelier, R. M.; Church, M. J.; White, A. E. The Diversity and functional potential of microbial communities associated with the colonial, $N_2$-fixing cyanobacterium Trichodesmium. ASLO Aquatic Sciences Meeting (017), Honolulu, HI, February-March 2017.


276. 2017 Lindh, M. V.; Church, M. J. There and back again - Unraveling mechanisms of microbial biogeography in the North Pacific Subtropical Gyre to and from Station ALOHA. ASLO Aquatic Sciences Meeting (040), Honolulu, HI, February-March 2017.


281. 2017 Olson, D. K.; Mende, D. R.; Aylward, F. O.; DeLong, E. F. Metagenomics reveals phylogenetic diversity and depth stratification of unique proteorhodopsin genes in shallow versus deep ocean waters at Station ALOHA. ASLO Aquatic Sciences Meeting (040), Honolulu, HI, February-March 2017.


284. 2017 Rii, Y. M.; Lindh, M. V.; Church, M. J. Diversity and dynamics of eukaryotic picoplankton in the North Pacific Subtropical Gyre. ASLO Aquatic Sciences Meeting (054), Honolulu, HI, February-March 2017.


287. 2017 Turk-Kubo, K. A.; Hogan, M. E.; Zehr, J. P.; Munoz-Marin, M. In-situ diazotroph net growth rates under different resource ratios at Station ALOHA. ASLO Aquatic Sciences Meeting (040), Honolulu, HI, February-March 2017.


291. 2017 White, A. E.; Watkins-Brandt, K. S. *Annual variability in the abundance and diversity of large diazotrophs at Station ALOHA*. ASLO Aquatic Sciences Meeting (040), Honolulu, HI, February-March 2017.


7.2 Invited/Contributed Book Chapters and Refereed Publications


41. 1994 Lukas, R. Interannual Variability of Pacific Deep and Bottom Waters Observed in the Hawaii Ocean Time-series. WOCE Notes, 6(2) 1, 3, 14-15.


73. 1996 Dore, J. E. and D. M. Karl. Nitrification in the euphotic zone as a source for nitrite, nitrate and nitrous oxide at Station ALOHA. Limnology and Oceanography 41(8), 1619-1628.


76. 1996 Firing, E. Currents observed north of Oahu during the first five years of HOT. Deep-Sea Research II 43, 281-303.


114. 1998 Li, W. K. W. Annual average abundance of heterotrophic bacteria and *Synechococcus* in surface ocean waters. Limnology and Oceanography 43(7), 1746-1753.


135. 1999 Scharek, R., L. Tupas and D. M. Karl. Diatom fluxes to the deep sea in the oligotrophic North Pacific gyre at Station ALOHA. Marine Ecology Progress Series 182, 55-67.


149. 2000 Lueker, T. J., A. G. Dickson and C. D. Keeling. Ocean pCO₂ calculated from dissolved inorganic carbon, alkalinity, and equations for K₁ and K₂: validation based on
laboratory measurements of CO₂ in gas and seawater at equilibrium. Marine Chemistry 70(1-3), 105-119.


397. 2008 Duennebier, F., D. Harris, and J. Jolly. ALOHA Cabled Observatory will Monitor Ocean in Real Time. Sea Technology, 49(2), 51-54.


2009 Greenwood, J. Shallow water dissolution of settling calcite at Station ALOHA. Limnology and Oceanography 54(5), 1420-1424.


diazotroph, *Trichodesmium*, from the Southwest Pacific Ocean. ISME Journal 3(11), 1286-1300.


468. 2009 Martiny, A. C., Y. Huang, W. Li. Occurrence of phosphate acquisition genes in Prochlorococcus cells from different ocean regions. Environmental Microbiology 11, 1340-1347.


644. 2014 Gradoville, R., A. White, D. Böttjer, M. Church, and R. Letelier. Diversity trumps acidification: No carbon dioxide enhancement of Trichodesmium community nitrogen or carbon fixation at Station ALOHA. Limnology and Oceanography, 59, 645-659.

645. 2014 Howe, B. M. A Deep Cabled Observatory: Biology and Physics in the Abyss. EOS, Transactions American Geophysical Union, 95 (47), 429-444.


reveals controls on N\textsubscript{2}-fixing microorganisms in the North Pacific Ocean. ISME Journal 8, 1175-1185.


2015 Martínez-García, S. and D. M. Karl. Microbial respiration in the euphotic zone at Station ALOHA. Limnology and Oceanography, 60, 1039-1050.


of the unicellular nitrogen-fixing cyanobacterium *Crocosphaera*. Nature Microbiology, 2, 17118.


7.3 Submitted Papers


7.4 Thesis and Dissertations


7.5 Data Reports and Manuals


School of Ocean and Earth Science and Technology, Univ. of Hawaii, Honolulu, HI, 156 pp.


7.6 Newsletters


12. 1992 Chiswell, S. Inverted echo sounders at the WOCE deep-water station. WOCE Notes, 4(4), 1, 3-6.


7.7 Symposia

1) Presentations from the "HOT Program: Progress and Prospectus" symposium, 3-4 June 1992, East-West Center, Honolulu, HI

a) Campbell, L. Bacterial numbers by flow cytometry: A new approach
b) Chiswell, S. Results from the inverted echo sounder network
c) Christian, J. Biomass closure in the epipelagic zone
d) Christian, J. Exoenzymatic hydrolysis of high molecular weight organic matter
e) Dore, J. Annual and short-term variability in the distribution of nitrite at the US-JGOFS time-series station ALOHA
f) Dore, J. and D. Hebel. Low-level nitrate and nitrite above the nutricline at Station ALOHA
g) Firing, E. Ocean currents near ALOHA
h) Hebel, D., R. Letelier and J. Dore. Evaluation of the depth dependence and temporal variability of primary production at Station ALOHA
i) Hebel, D., R. Letelier and J. Dore. Past and present dissolved oxygen trends, methodology, and quality control during the Hawaii Ocean Time series
j) Hebel, D. and U. Magaard. Structure and temporal variability in biomass estimates at Station ALOHA
k) Houlihan, T. and D. Hebel. Organic and inorganic nutrients: Water column structure and usefulness in time-series analysis
l) Karl, D. Carbon utilization in the mesopelagic zone: AOU-DOC relationships
m) Karl, D. HOT/JGOFS program objectives: A brief overview
n) Karl, D. P-control of N2 fixation: An ecosystem model
o) Karl, D. Primary production and particle flux
p) Karl, D. et al. Review and re-assessment of core measurements: Suggestions for refinement and improvement
q) Karl, D. and G. Tien. Low-level SRP above the nutricline at Station ALOHA
s) Karl, D., K. Yanagi and K. Bjorkman. Composition and turnover of oceanic DOP
t) Letelier, R. Temporal variability of algal accessory pigments at Station ALOHA: What does it tell about the phytoplankton community structure at the DCML?
u) Letelier, R. and D. Hebel. Evaluation of fluorometric and HPLC chlorophyll a measurements at Station ALOHA
v) Letelier, R. and F. Santiago-Mandujano. Wind, sea surface temperature and significant wave height records from NDBC buoy #51001 compared to ship observations at Station ALOHA
w) Lukas, R. Water mass variability observed in the Hawaii Ocean Time-series
x) Sadler, D., C. Winn and C. Carrillo. Time-series measurements of pH: A new approach for HOT
y) Schudlich, R. Upper ocean gas modelling at Station ALOHA
z) Winn, C. DIC variability
aa) Winn, C. and C. Carrillo. DIC and alkalinity profiles and elemental ratios

2) Presentations from the "HOT Golden Anniversary Science Symposium," 16 November 1993, East-West Center, Honolulu, HI
   a) Bingham, F. M. The oceanographic context of HOT
   b) Campbell, L., H. Nolla, H. Liu and D. Vaulot. Phytoplankton population dynamics at the Hawaii Ocean Time series Station ALOHA
   c) Campbell, L., H. Nolla and D. Vaulot. The importance of Prochlorococcus to community structure in the central North Pacific Ocean
   d) Christian, J. Vertical fluxes of carbon and nitrogen at Station ALOHA
   e) Dore, J. Nitrate diffusive flux cannot support new production during quiescent periods at Station ALOHA
   f) Dore, J. Nitrification in lower euphotic zone at Station ALOHA: Patterns and significance
   g) Firing, E. The north Hawaiian ridge current and other flows near ALOHA
   h) Hebel, D. Temporal distribution, abundance and variability of suspended particulate matter (particulate carbon, nitrogen and phosphorus) at Station ALOHA -- Observations of a seasonal cycle
   i) Karl, D., D. Hebel, L. Tupas, J. Dore and C. Winn. Station ALOHA particle fluxes and estimates of export production
   j) Karl, D. M., R. Letelier, L. Tupas, J. Dore, D. Hebel and C. Winn. N2 fixation as a contributor to new production at Station ALOHA
   k) Karl, D. M., G. Tien and K. Yanagi. Phosphorus dynamics at Station ALOHA
   l) Kennan, S. C. Possibilities for stirring along the Hawaiian ridge
   m) Krothapalli, S., Y. H. Li and F. T. Mackenzie. What controls the temporal variability of carbon flux at Station ALOHA?
   n) Letelier, R. M. Inorganic carbon assimilation at Station ALOHA: Possible evidence of a change in carbon fluxes
   o) Letelier, R. M. Spatial and temporal distribution of Trichodesmium sp. at Station ALOHA: How important are they?
   p) Liu, H. and L. Campbell. Measurement of growth and mortality rates of Prochlorococcus and Synechococcus at Station ALOHA using a new selective inhibitor technique
   q) Lukas, R. and F. Bingham. Annual and interannual variations of hydrographic properties observed in the Hawaii Ocean Time-series (HOT)
r) Lukas, R., F. M. Bingham and A. Mantyla. An anomalous cold event in the bottom water observed at Station ALOHA

s) Moyer, C. L., L. Campbell, D. M. Karl and J. Wilcox. Restriction fragment length polymorphism (RFLP) and DNA sequence analysis of PCR-generated clones to assess diversity of picoeukaryotic algae in the subtropical central North Pacific Ocean (Station ALOHA)

t) Polovina, J. J. and D. R. Kobayashi. HOT and Hawaii's fisheries landings: Complementary or independent time-series?

u) Sadler, D. Time series measurement of pH at Station ALOHA

v) Smith, C. R., D. J. DeMaster, R. H. Pope, S. P. Garner, D. J. Hoover and S. E. Doan. Seabed radionuclides, bioturbation and benthic community structure at the Hawaii Ocean Time-series Station ALOHA

w) Tupas, L. M., B. N. Popp and D. M. Karl. Dissolved organic carbon in oligotrophic waters: Experiments on sample preservation, storage and analysis

x) Winn, C. D. Air-sea carbon dioxide exchange at Station ALOHA

y) Yuan, J. and C. I. Measures. Sampling and analysis of dissolved iron

3) Presentations from the "HOT-75 Commemorative Science Symposium," 9 September 1996, East-West Center, Honolulu, HI

a) Atkinson, M. A Potentiostatic, Solid-state Oxygen Sensor for Oceanic CTDs


c) Campbell, L., H. Liu, H. Nolla and D. Vaulot. Annual Variability of Phytoplankton and Bacteria in the Subtropical North Pacific Ocean at Station ALOHA during the 1991-1994 ENSO Event


e) Dore, J. and D. Karl. Nitrification, New Production and Nitrous Oxide at Station ALOHA

f) Ducklow, H. Joint Global Ocean Flux Study -- Vision and Progress

g) Emerson, S., C. Stump and D. Wilber. Inert Gases as Tracers of Diapycnal Mixing in the Upper Ocean

h) Firing, E. Currents in the Vicinity of Station ALOHA: An Update

i) Fujieki, L. HOT-DOGS: A New Tool for HOT Program Data Base Analysis and Presentation

j) Hebel, D., L. Tupas and D. Karl. The Importance of Organic Exudates in the Measurement of Oligotrophic Ocean Primary Productivity

k) Karl, D., D. Hebel and L. Tupas. Regionalization of Station ALOHA

l) Karl, D., G. Tien, K. Björkman, K. Yanagi, R. Letelier, A. Colman and A. Thomson. The "Forgotten" Open Ocean P-Cycle

n) Landry, M., K. Selph and H. Al-Mutairi. *Seasonal and Diurnal Variability of the Mesozooplankton Community at Ocean Station ALOHA*


p) Liu, H., L. Campbell and H. Nolla. *Prochlorococcus Growth Rate and Daily Variability at Station ALOHA*

q) Lopez, M. and M. Huntley. *Particle Concentrations at the Hawaii Ocean Time-series Station (Station ALOHA) Measured with an Optical Plankton Counter*

r) Michaels, A. and A. Knap. *The Bermuda Atlantic Time-Series Study (BATS): A View from the "Other" Ocean*


t) Quay, P. and H. Anderson. *A Dissolved Inorganic Carbon Budget at Station ALOHA*

u) Santiago-Mandujano, F. and R. Lukas. *Cold Bottom Water Events Observed in the Hawaii Ocean Time-Series: Modelling and Implications for Vertical Mixing*

v) Scharek, R., M. Latasa, D. Karl and R. Bidigare. *Vertical Flux of Diatoms at the JGOFS/WOCE Station ALOHA*

w) Smith, C., R. Miller, R. Pope and D. DeMaster. *Seafloor Inventories of Pb-210, Th-234 and Benthic Biomass as Proxies for Deep POC Flux: Placing Export Production at the HOT Station in a General Oceanic Context*

x) Tien, G., D. Pence and D. Karl. *Hydrogen Peroxide Measurements at Station ALOHA*

y) Tupas, L., G. Tien, D. Hebel and D. Karl. *Dissolved Organic Carbon Dynamics in the Upper Water Column at Station ALOHA*

z) Vink, S., K. Falkner, V. Tersol, J. Yuan and C. Measures. *Variations in Iron, Aluminum, Beryllium and Barium Concentrations in Surface Waters at Station ALOHA*

aa) Winn, C. *Secular Changes in Inorganic Carbon Parameters at HOT and BATS*

4) Ocean Carbon & Biogeochemistry - Sea Change: Charting the Course for Ecological and Biogeochemical Ocean Time Series Research, 21-23 September 2010, Honolulu, HI

a) Welcome/Introduction/Workshop objectives (Matthew Church, UH)

b) The Bermuda Atlantic Time-series Study (Michael Lomas, BIOS)

c) The Hawaii Ocean Time-series (Matthew Church, UH)

d) The CARIACO Oceanographic Time-Series Program (Frank Muller-Karger, USF)

e) Plenary 1: Cross ecosystem perspectives on aquatic biogeochemistry and plankton community structure (Robert Sterner, University of Minnesota)
f) Ocean Biogeochemistry Research Opportunities Using the Ocean Observatories Initiative Infrastructure (Kendra Daly)

g) An update on the European network of marine observatories (Richard Lampitt)

h) The Ocean Time Series Advisory Committee (OTSAC): An introduction (Ken Johnson)

i) Evening plenary: "The Joy of ocean Time-Series" (David Karl, University of Hawaii)

j) Plenary 2: Biogeochemical and ecological coupling or decoupling of the epipelagic and deep sea: regional to global implications (Richard Lampitt, NOC, Southampton)

k) Plenary 3: Autonomous platform time series (Ken Johnson, MBARI)

l) Plenary 4: Ocean-time series as windows into scales of variability in the sea (Francisco Chavez, MBARI)

m) Concluding remarks (Matthew Church, UH)

5) Station ALOHA: Celebrating 25 years of sustained ocean observations, Ocean Sciences Meeting - Session 049, 23-28 February 2014, Honolulu, HI

**Oral Presentations**


b. Lukas, R.; Santiago-Mandujano, F. E.; Plueddemann, A. J.; Weller, R. A.; Duennebier, F. K.; [Quantifying the surface freshwater flux at Station ALOHA](#)

c. Dore, J. E.; Sadler, D. W.; HOT CO₂ team, T.; [The HOT program presents: A Carbon Carol: ghosts of CO₂ past, CO₂ present and CO₂ yet to come](#)

d. Fitzsimmons, J. N.; Zhang, R.; Boyle, E. A.; [Short- and long-term temporal variability of iron at Station ALOHA](#)

e. Zehr, J. P.; Carter, B. J.; Foster, R. A.; Thompson, A. W.; Tripp, H. J.; [Same stage but different actors: 20 Years of change in Nitrogen fixation at Station ALOHA](#)

f. Bryant, J. B.; Eppley, J. M.; Karl, D. M.; Church, M. J.; DeLong, E. F.; [Wind and season drive microbial community diversity in the North Pacific Subtropical Gyre at Station ALOHA](#)

g. Barone, B.; Church, M. J.; Karl, D. M.; Letelier, R. M.; White, A. E.; [Size structure and particle maxima in different layers of the water column of a Subtropical Gyre: Influences of algal ecology and density stratification](#)

h. Karl, D. M.; Clemente, T.; Grabowski, E.; Wilson, S. T.; Church, M. J.; [Variability in particle export at Station ALOHA](#)

**Poster Presentations**

i. Foley, J. M.; [Taking Time-series to the streets: Educational programs that communicate Station ALOHA research](#)
j. Luo, Y. W.; Nicholson, D. P.; Doney, S. C.; High-Frequency biogeochemical modeling based on HOE-DYLAN experiment at Station ALOHA

k. Duhamel, S.; Björkman, K. M.; Doggett, J. K.; Karl, D. M.; Microbial group specific uptake of Inorganic phosphate and ATP at Station ALOHA: Kinetics, effect of light and response to rapid changes in N:P availability

l. Hayes, C. T.; Boyle, E. A.; McGee, D.; Fitzsimmons, J. N.; Anderson, R. F.; $^{232}\text{Th}/^{230}\text{Th}$ at the Hawaii Ocean Time-series Station ALOHA: A Tool for iron cycling

m. Fontanez, K. M.; DeLong, E. F.; Microbial community structure and function on sinking particles at Station ALOHA

n. Martinez-Garcia, S.; Karl, D. M.; Euphotic and mesopelagic zone microbial respiration at Station ALOHA


p. Church, M. J.; HOT Team, T.; The Hawaii Ocean Time-series (HOT) program turns 25: Highlights of a quarter century of sustained observations in the sea

q. Segura-Noguera, M.; Curless, S. E.; Church, M. J.; Karl, D. M.; Ammonium distribution at Station ALOHA in the North Pacific Subtropical Gyre

r. Letelier, R. M.; White, A. E.; Church, M. J.; Karl, D. M.; Bidigare, R. R.; Local to basin scale modulation of primary productivity in the North Pacific Subtropical Gyre: Lessons learned from the Hawaii Ocean Time-series program

s. Wai, B. R.; Church, M. J.; Karl, D. M.; DeLong, E. F.; Temporal variability of ammonia-oxidizing archaea at Station ALOHA

t. Doggett, J. K.; van den Engh, G.; Doblin, M. A.; Karl, D. M.; High-resolution flow cytometry profiles of Prochlorococcus at Station ALOHA

u. Sadler, D. W.; Dore, J. E.; Church, M. J.; Fujieki, L. A.; Karl, D. M.; Assessing the internal consistency of CO$_2$ measurements at Station ALOHA

v. Viviani, D. A.; Church, M. J.; Dissolved organic matter production and microbial growth at Station ALOHA

w. Curless, S. E.; Björkman, K. M.; Updyke, B.; Mahaffey, C.; Dore, J. E.; Analyses of inorganic nutrient pools by the Hawaii Ocean Time-series (HOT) program: methods, procedures, and standardization

x. Howe, B. M.; Lukas, R.; ALOHA Cabled Observatory: On-going results and new instruments

6) Station ALOHA: A Sentinel of open ocean change, ASLO Aquatic Sciences Meeting - Session 040, 26 February - 3 March 2017, Honolulu, HI

**Oral Presentations**

b. Liu, X.; Levine, N. M.; *Impact of fine-scale physics on marine ecosystem and carbon dynamics in the North Pacific Subtropical Gyre: Perspectives from a new modeling approach*
d. Ferron, S.; Barone, B.; Church, M. J.; Karl, D. M.; *Biological oxygen production in the North Pacific Subtropical Gyre*
e. White, A. E.; Watkins-Brandt, K. S.; *Annual variability in the abundance and diversity of large diazotrophs at Station ALOHA*
f. Eichner, M.; Klawonn, I.; Wilson, S. T.; Littmann, S.; Whitehouse, M.; Church, M. J.; Kuypers, M. M.; Karl, D. M.; Ploug, H.; *Distinct microenvironments and high single-cell variability in Trichodesmium colonies collected at Station ALOHA*
g. Follett, C. L.; White, A. E.; Follows, M. J.; *Nitrogen fixation measured by stoichiometric fluctuations*
h. Church, M. J.; Björkman, K. M.; Karl, D. M.; Rii, Y. M.; Viviani, D. A.; *Emerging views on picoplankton dynamics at Station ALOHA*
j. Bryant, J. A.; Mende, D. R.; Aylward, F. O.; Eppley, J. M.; Nielsen, T. N.; DeLong, E. F.; *A Genomic inflection point in the twilight zone of the ocean's interior*
k. Valencia, B.; Landry, M. R.; Decima, M.; Hannides, C. C.; *Environmental drivers of mesozooplankton biomass variability at Station ALOHA, North Pacific Subtropical Gyre*
l. Olson, D. K.; Mende, D. R.; Aylward, F. O.; DeLong, E. F.; *Metagenomics reveals phylogenetic diversity and depth stratification of unique proteorhodopsin genes in shallow versus deep ocean waters at Station ALOHA*

**Poster Presentations**

m. Grabowski, E. M.; Karl, D. M.; *Caloric content of Sinking particulate matter in the North Pacific Subtropical Gyre*

n. Rosburg, K. C.; Potemra, J. T.; Santiago-Mandujano, F.; Lukas, R.; Weller, R. A.; Plueddemann, A. J.; *Comparison of observed and independently-derived upper ocean currents at Station ALOHA*
o. Lindh, M. V.; Church, M. J.; *There and back again - Unraveling mechanisms of microbial biogeography in the North Pacific Subtropical Gyre to and from Station ALOHA*


q. Björkman, K. M.; Duhamel, S.; Church, M. J.; Karl, D. M.; *Spatial and temporal variability in phosphorus inventories and turnover of inorganic P and adenosine-triphosphate in the North Pacific*

r. Curless, S. E.; Church, M. J.; Segura-Noguera, M.; Karl, D. K.; *Ammonium concentrations at Station ALOHA - Improved methodology allows for full ocean depth analysis*

s. Sadler, D. W.; Barone, B.; Burkitt, J. W.; Dore, J. E.; Church, M. J.; Karl, D. M.; *High-resolution in-situ pH measurements at Station ALOHA using an ion-sensitive field effect transistor*

t. Luo, E.; Eppley, J. M.; Aylward, F. O.; Romano, A. R.; DeLong, E. F.; *Vertical variability in viral and host assemblages at Station ALOHA*

u. Viviani, D. A.; Böttjer, D.; Letelier, R. M.; Church, M. J.; *The Influence of abrupt increases in seawater pCO₂ on rates of microbial production in the subtropical North Pacific Ocean*

v. Royer, S. J.; Ferron, S.; Wilson, S. T.; del Valle, D. A.; Sosa, O.; Karl, D. M.; *Methane production from sinking particulate matter at Station ALOHA*

w. Turk-Kubo, K. A.; Hogan, M. E.; Zehr, J. P.; Munoz-Marin, M.; *In-situ diazotroph net growth rates under different resource ratios at Station ALOHA*
8.0 DATA AVAILABILITY AND DISTRIBUTION

Data collected by HOT program scientists are made available to the oceanographic community in various ways as soon after processing as possible. The complete data set, containing data collected since year 1 of the HOT program (1988-89), as well as 2 dbar averaged CTD data, may be accessed using anonymous File Transer Protocol (FTP) or the World Wide Web (WWW).

8.1 File Transfer Protocol

In order to maximize ease of access, the data are in ASCII files.

The workstation's Internet address is ftp://ftp.soest.hawaii.edu. The data are in a subdirectory called /hot. More information about the data base is given in several files called Readme.* at this level. The file Readme.first gives general information on the data base; we encourage users to read it first.

The following is an example of how to use FTP to obtain HOT data.

2. Enter anonymous as the user name.
3. Enter your e-mail address as the password.
4. The HOT database is in /hot.
5a. To obtain information about the database, view Readme.first.
5b. To obtain 2-decibar averaged CTD data, change directories to ctd/hot-#, where # is the HOT cruise of interest.
5c. To obtain water column data, change directories to water. For each cruise, 2 files are provided. The hot#.gof files contain all of the physical and biogeochemical data, while the hot#.sea files only contain the physical and inorganic nutrient data.

To access hydrographic data from recent cruises (data preliminarily calibrated and quality controlled), the user is required to submit a simple registration form available at https://hahana.soest.hawaii.edu/hot/register/regis-form.php. After submitting the registration form, an e-mail will be sent to the user with further instructions on how to access the data.

8.2 World Wide Web

The Hawaii Ocean Time-series Program maintains a site on the World Wide Web where data and information about the program and its activities can easily be accessed over the Internet.
The address is [https://hahana.soest.hawaii.edu/hot/hot.html](https://hahana.soest.hawaii.edu/hot/hot.html). The first half of the most recent year’s hydrographic data is usually available by July and the second half by January of the following year with certain quality control caveats. All available data are quality controlled by around July of the following year. Downloading of data is through FTP but the web pages provide a more detailed means of access.

8.3 **HOT-DOGS**

HOT-DOGS is the acronym for the Hawaii Ocean Time-series Data Organization and Graphical System. It’s address is [https://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html](https://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html). HOT-DOGS is a Matlab™ based program that displays HOT data in a graphical format as depth profiles, time-series or contour plots. In addition to its graphical capabilities, HOT-DOGS provides a means of downloading selected data parameters during specific years of the program. The user may perform the following:

- **Data Extraction**
  - *Bottle* (discrete)
  - *CTD* (continuous)
  - *Macronzooplankton* (Nets)
  - *Epi-Fluorescence Microscopy*
  - *Particle Flux*
  - *Primary Production*

- **Display**
  - *Bottle* (discrete)
  - *CTD* (continuous)
  - *HPLC Pigments*
  - *Epi-Fluorescence Microscopy*
  - *Particle Flux*
  - *Primary Production*
  - *Solar Irradiance*
  - *PRR (Ir)radiance*
  - *Hyperspectral (Ir)radiance*
  - *TSRB (Ir)radiance*
  - *Fast Repitition Rate Fluorometry*
  - *Laser In-Situ Scattering & Transmissometry*
  - *Absorption Spectra (PUR)*
  - *Chlorofluorocarbon & Sulfur Hexafluoride*
  - *Underway Measurements*
  - *User Defined*
• **Standard Intervals** (vertical Water-Column)
  • Bottle (discrete)
  • HPLC Pigments
  • Epi-Fluorescence Microscopy
  • Primary Production
  • User Defined

• **Time-series**
  • Bottle (discrete)
  • HPLC Pigments
  • Macrozooplankton (Nets)
  • Epi-Fluorescence Microscopy
  • Particle Flux
  • Primary Production
  • (Ir)radiance
  • User Defined

• **Contour**
  • Bottle (discrete)
  • CTD (continuous)
  • HPLC Pigments
  • Epi-Fluorescence Microscopy
  • Primary Production
  • User Defined

• **Miscellaneous**
  • Mixed-layer Depth
  • Cruise Summary
Figure 6.1.1a
Figure 6.1.1b
Figure 6.1.1c
Figure 6.1.1g
Figure 6.1.1h
Figure 6.1.1i
Figure 6.1.2a
Figure 6.1.2b
Figure 6.1.2c
Figure 6.1.2f
Figure 6.1.2h
Figure 6.1.2i
Figure 6.1.3a
Figure 6.1.3c
Figure 6.1.3d
Figure 6.1.3e
Figure 6.1.3f
Figure 6.1.3g
Figure 6.1.3h
Kahe Pt. HOT 309

Pressure (dbar)

Potential Temperature (°C)

Temperature (°C)

Salinity

Oxygen (μmol/kg)

σθ (kg/m³)
Figure 6.1.4b
Figure 6.1.4d
Figure 6.1.4e
Kahe Pt. HOT 314

Figure 6.1.4f
Figure 6.1.4g
Figure 6.1.4i
HOT 309-317 WOCE deep casts

Figure 6.1.5
Figure 6.1.7
HOT 1–317 Potential Temperature

Figure 6.1.8
Figure 6.1.21

HOT 1–317 Soluble Reactive Phosphorus [umol/kg]
Figure 6.2.1a
Figure 6.2.1b
Figure 6.2.1c
HOT-312 Thermosalinograph, \( o = \) CTD at 6 dbar, \( x = \) salinity bottle

Figure 6.2.1d
HOT-313 Thermosalinograph, o=CTD at 6 dbar, x=salinity bottle

Figure 6.2.1e
HOT-314 Thermosalinograph, o=CTD at 6 dbar, x=salinity bottle

![Graphs of temperature, salinity, and $\sigma_\theta$ over August 2019 (UTC)](image)

Figure 6.2.1f
HOT-315 Thermosalinograph, $\sigma$=CTD at 6 dbar, $x$=salinity bottle

Temperature (°C)

Salinity

$\sigma_\theta$

September 2019 (UTC)

Figure 6.2.1g
Figure 6.2.1h
HOT-317 Thermosalinograph, o=CTD at 6 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

Figure 6.2.1i
HOT-309 Navigation and Ship Speed

Latitude (N):

Longitude (W):

Ship Speed (m/s):

January 2019 (UTC)

Figure 6.2.2a
HOT-310 Navigation and Ship Speed

Figure 6.2.2b
HOT-311 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

May 2019 (UTC)

Figure 6.2.2c
HOT-312 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

June 2019 (UTC)

Figure 6.2.2d
HOT-313 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

June-July 2019 (UTC)

Figure 6.2.2e
HOT-314 Navigation and Ship Speed

**Latitude (N)**

**Longitude (W)**

**Ship Speed (m/s)**

August 2019 (UTC)

Figure 6.2.2f
Figure 6.2.2g
HOT-316 Navigation and Ship Speed

October 2019 (UTC)

Figure 6.2.2h
HOT-317 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

December 2019 (UTC)

Figure 6.2.2i
HOT 309–317 Atmospheric Pressure

Sea Surface Temperature

Figure 6.3.1
HOT 309 - Shipboard Winds, Observed

HOT 309 - Shipboard Winds, from the continuous record of the ship

HOT 309 - True Winds, WHOTS buoy data

Figure 6.3.4a
HOT 310 - Shipboard Winds, Observed

HOT 310 - Shipboard Winds, from the continuous record of the ship

HOT 310 - True Winds, WHOTS buoy data

Figure 6.3.4b
HOT 311 - Shipboard Winds, Observed

5.0 m/s

HOT 311 - Shipboard Winds, from the continuous record of the ship

5.0 m/s

HOT 311 - True Winds, WHOTS buoy data

5.0 m/s
HOT 312 - Shipboard Winds, Observed

HOT 312 - Shipboard Winds, from the continuous record of the ship

HOT 312 - True Winds, WHOTS buoy data

Figure 6.3.4d
HOT 313 - Shipboard Winds, Observed

HOT 313 - Shipboard Winds, from the continuous record of the ship

HOT 313 - True Winds, WHOTS buoy data

Figure 6.3.4e
HOT 314 - Shipboard Winds, Observed

HOT 314 - Shipboard Winds, from the continuous record of the ship

HOT 314 - True Winds, WHOTS buoy data

5.0 m/s
HOT 315 - Shipboard Winds, Observed

HOT 315 - Shipboard Winds, from the continuous record of the ship

HOT 315 - True Winds, WHOTS buoy data

Figure 6.3.4g
HOT 316 - Shipboard Winds, Observed

5.0 m/s

HOT 316 - Shipboard Winds, from the continuous record of the ship

5.0 m/s

HOT 316 - True Winds, WHOTS buoy data

5.0 m/s

Figure 6.3.4h
HOT 317 - Shipboard Winds, Observed

HOT 317 - Shipboard Winds, from the continuous record of the ship

HOT 317 - True Winds, WHOTS buoy data

Figure 6.3.4i
Harmonic Analysis of Velocity

- **mean + trend**: 0.1 m/s
- **semidiurnal**: 12.42 hours
- **diurnal**: 24 hours
- **inertial**: 31 hours

Figure 6.4.1a
Harmonic Analysis of Velocity

- mean + trend
- semidiurnal 12.42 hours
- diurnal 24 hours
- inertial 31 hours
Velocity On Station

HOT-311

2019 Days

Depth (m)

mean
+ trend
semidiurnal 12.42 hours
diurnal 24 hours

Harmonic Analysis of Velocity

Figure 6.4.1c
Figure 6.4.1d
Figure 6.4.1e
Velocity On Station

HOT−314

Harmonic Analysis of Velocity

mean + trend
semidiurnal 12.42 hours
diurnal 24 hours
inertial 31 hours

Figure 6.4.1f
Velocity On Station

2019 Days

Depth (m)

HOT-315

Harmonic Analysis of Velocity

mean + trend
semidiurnal 12.42 hours
diurnal 24 hours

0
0.1 m/s

Figure 6.4.1g
Figure 6.4.1h
Figure 6.4.1i
Figure 6.4.2a
Figure 6.4.2b
Figure 6.4.2c
Figure 6.4.2d
Figure 6.4.2e
Figure 6.4.2f
Figure 6.4.2g
Figure 6.4.2h
Figure 6.4.2i
Figure 6.5.5
Figure 6.5.6

HOT 1-317 Low-Level NO₂ + NO₃ [nmol kg⁻¹]

Pressure [mbars]

Sampling Date
Figure 6.5.7
Figure 6.5.7 continued
HOT 1-317 Low-Level Phosphorus [nmol kg⁻¹]

Pressure [dbars]

Sampling Date

Figure 6.5.8
HOT 1–317 (0–50 dbar means)

HOT 1–317 (50–100 dbar means)

Particulate Carbon [μmol kg$^{-1}$]

Sampling Date

Figure 6.5.10
Figure 6.5.11
HOT 1–317 (0–50 dbar means)

Particulate Nitrogen [μmol kg$^{-1}$]

Sampling Date

HOT 1–317 (50–100 dbar means)

Particulate Nitrogen [μmol kg$^{-1}$]

Sampling Date

Figure 6.5.12
HOT 79–317 (0–50 dbar means)

HOT 79–317 (50–100 dbar means)

Particulate Silica [nmol kg⁻¹]

Sampling Date

Figure 6.5.16
HOT 1-308 Chlorophyll a [µg m$^{-3}$]

HOT 1-308 Chlorophyll b [µg m$^{-3}$]

HOT 1-308 Chlorophyll c [µg m$^{-3}$]

Figure 6.5.19
HOT 1-308 19'-Butanoyloxyfucoxanthin [$\mu$g m$^{-3}$]

HOT 1-308 Fucoxanthin [$\mu$g m$^{-3}$]

HOT 1-308 19'-Hexanoyloxyfucoxanthin [$\mu$g m$^{-3}$]

Figure 6.5.20
Figure 6.5.21
Figure 6.6.1
HOT 1–317

Carbon Flux (mg C m⁻² d⁻¹)

Nitrogen Flux (mg N m⁻² d⁻¹)

Phosphorus Flux (mg P m⁻² d⁻¹)

Silica Flux (mg S m⁻² d⁻¹)

Sampling Date

Figure 6.6.3
HOT−309, int = 21.65 [E m^{-2} d^{-1}]

Figure 6.7.1a
HOT–311, int = 45.40 [E m⁻² d⁻¹]

Figure 6.7.1c
HOT–312, int = 56.82 [E m$^{-2}$ d$^{-1}$]

Figure 6.7.1d
HOT−315, int = 46.65 [E m$^{-2}$ d$^{-1}$]

Figure 6.7.1g
Figures 6.7.1i
HOT 90–317 1% Light Level

HOT 90–317 (100–150 m means)

Figure 6.7.2
Figure 6.7.3
Figure 6.8.1
Figure 6.8.1 continued
Figure 6.8.3
Figure 6.8.3 continued
HOT 51–317

Figure 6.9.1
Temperature (°C)

Salinity

σ_θ (kg m⁻³)

Oct18  Dec18  Jan19  Mar19  May19  Jun19  Aug19  Oct19

Figure 6.10.1.a
Temperature (°C)

Salinity

$\sigma_\theta$ (kg m$^{-3}$)

Figure 6.10.1.d
Temperature (°C)

Salinity

\(\sigma_\theta\) (kg m\(^{-3}\))

**Figure 6.10.1.f**
Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.k
Temperature (°C)

WHOTS−15.95 m. SN 3791

Salinity

σθ (kg m$^{-3}$)

Oct18  Dec18  Jan19  Mar19  May19  Jun19  Aug19  Oct19

Figure 6.10.1.m
Temperature (°C)

Salinity

σθ (kg m$^{-3}$)

WHOTS-15,135 m. SN 2965

Oct18 Dec18 Jan19 Mar19 May19 Jun19 Aug19 Oct19

Figure 6.10.1.p
Figure 6.10.1.r
WHOTS-15 Microcat Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.t
WHOTS−15 300 kHz ADCP, Zonal Current (m s\(^{-1}\))

ADCP, Meridional Current (m s\(^{-1}\))

Figure 6.10.2.b
WHOTS-15 NGVM Zonal Current at 10 m

NGVM, Zonal Current at 30 m

NGVM Meridional Current at 10 m

NGVM, Meridional Current at 30 m

Figure 6.10.3
Figure 6.10.4.a
WHOTS–16 Cruise CTD Yo–Yo : Station 50 Cast 3

WHOTS–16 Cruise CTD Yo–Yo : Station 50 Cast 4

Figure 6.10.4.b
Figure 6.10.4.c
Figure 6.10.4.d
Figure 6.10.4.e
HOT-309 Red - Port anemometer; Blue - Starboard anemometer

Red - Port anemometer; Blue - Starboard anemometer
o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Figure 6.10.5.a.1
HOT-309 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

PSP SW W/m²

PIR LW W/m²

PAR W/m²

Red line = RM Young RTD, Blue line = Humidity Temp, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Air Temp °C

Humidity %

Day (2019)

Figure 6.10.5.a.2
HOT-309 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Figure 6.10.5.a.3
Figure 6.10.5.b.1
Figure 6.10.5.b.2
HOT-310 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42
HOT-311 Red - Port anemometer; Blue - Starboard anemometer

Rel Wind Spd
m/s

Rel Wind Dir
m/s

Ship Speed
m/s

Red - Port anemometer; Blue - Starboard anemometer
o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

True Wind Spd
m/s

True Wind Dir
m/s

Day (2019)

120.5 121 121.5 122 122.5 123 123.5 124 124.5 125

Figure 6.10.5.c.1
Figure 6.10.5.c.2
HOT-311 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Figure 6.10.5.c.3
HOT-312 Red - Port anemometer; Blue - Starboard anemometer

Relative Wind Speed (m/s)

Relative Wind Direction

Ship Speed

Red - Port anemometer; Blue - Starboard anemometer
o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

True Wind Speed (m/s)

True Wind Direction

Day (2019)

Figure 6.10.5.d.1
Figure 6.10.5.d.3
Figure 6.10.5.e.1
Figure 6.10.5.e.2
Figure 6.10.5.f.2
HOT-314 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Figure 6.10.5.f.3
HOT-315 Red - Port anemometer; Blue - Starboard anemometer

Rel Wind Spd m/s

Rel Wind Dir m/s

Ship Speed m/s

Red - Port anemometer; Blue - Starboard anemometer
o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

True Wind Spd m/s

True Wind Dir m/s

Day (2019)

Figure 6.10.5.g.1
HOT-315 Red line = Kilo Moana, o = WHOTS-15 Logger #19, x = WHOTS-15 Logger #42

Figure 6.10.5.g.3
HOT-317 Red - Port anemometer; Blue - Starboard anemometer

Relative Wind Speed (m/s)

Relative Wind Direction (°)

Ship Speed (m/s)

Red - Port anemometer; Blue - Starboard anemometer
'o' = WHOTS-16 Logger #7, 'x' = WHOTS-16 Logger #8

True Wind Speed (m/s)

True Wind Direction (°)

Day (2019)

Figure 6.10.5.h.1