Hawaii Ocean Time-series
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Lance A. Fujieki
Fernando Santiago-Mandujano
Kellen Rosburg
Andrew King
Roger Lukas
David Karl

with contributions by:
Robert Bidigare
Karin Björkman
Matthew Church
John Dore
Michael Landry
Ricardo Letelier

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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 2015. However, we have included some data from 1988-2014 to place the 2015 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, thermosalinograph and ADCP observations, as well as meteorological, temperature, salinity and current observations from the WHOTS mooring. The complete data set resides on a pair of Workstations 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. These files are also available in our public ftp site (mananui.soest.hawaii.edu/pub/hot/netcdf).
ACKNOWLEDGMENTS

Many people participated in the 2015 cruises sponsored by the HOT program. Special thanks are due to James Burkitt, Tara Clemente, Susan Curless, Robert (Walt) Deppe, Brie Maillot, Daniel McCoy, Alexa Nelson, Dan Sadler, Eric Shimabukuro, Jeffrey Snyder, Brenner Wai and Blake Watkins for the tremendous amount of time and effort they have put into the program. Special thanks are given to Georgia Tanaka, Jennifer Kondo and Kellie Terada for their 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, Susan Curless and Brenner Wai performed the nutrient analyses. Dan Sadler performed the carbon analyses. Daniel McCoy and R. Walter Deppe performed the salinity measurements. Kyle Kurata, Adela Dumitrascu and Casey Moss 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 Ka‘imikai-O-Kanaloa, the R/V Kilo Moana, the NOAA ship Hi‘ialakai 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 2015 work is NSF grant OCE-12-60164 (Church, Bidigare, Karl and Lukas). Additional support for HOT Research was provided by the Simons Foundation. The WHOTS program work was funded in part by the Ocean Observing and Monitoring Division, Climate Program Office (FundRef number 100007298), and the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, under grant NA14OAR4320158 to the Woods Hole Oceanographic Institution. This work was also supported by NSF grants OCE-0327513 and OCE-752606.
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 CO₂ 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., CO₂), 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 Matthew Church, David Karl, and Robert Bidigare contribute expertise in plankton biogeochemistry and ecology, and Roger Lukas 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 measurements of inherent optical properties and satellite remote sensing. 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 2015

<table>
<thead>
<tr>
<th>Scientists</th>
<th>Project role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert R. Bidigare (co-PI)</td>
<td>Biogeochemistry and ecology component</td>
</tr>
<tr>
<td>Matthew J. Church (lead-PI)</td>
<td>Biogeochemistry and ecology component</td>
</tr>
<tr>
<td>John Dore (collaborator)</td>
<td>Inorganic carbon</td>
</tr>
<tr>
<td>David M. Karl (co-PI)</td>
<td>Biogeochemistry and ecology component</td>
</tr>
<tr>
<td>Michael Landry (collaborator)</td>
<td>Biogeochemistry and ecology component</td>
</tr>
<tr>
<td>Ricardo Letelier (collaborator)</td>
<td>Zooplankton and plankton community structure</td>
</tr>
<tr>
<td>Roger B. Lukas (co-PI)</td>
<td>Inherent optical properties and satellite remote</td>
</tr>
<tr>
<td></td>
<td>sensing</td>
</tr>
<tr>
<td>Robert Weller &amp; Al Plueddmann</td>
<td>Physical oceanography component</td>
</tr>
<tr>
<td>(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-BEACH web page (hahana.soest.hawaii.edu/hot/ancillary.html).
Table 1.2: Ancillary Projects Supported by HOT in 2015

<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 &amp; Ricardo Letelier</td>
<td>UH</td>
<td>NSF</td>
<td>Nitrogen fixation in a high CO₂ world</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, DeLong &amp; others</td>
<td>Various</td>
<td>SF</td>
<td>Simons Collaboration on Ocean Processes and Ecology</td>
</tr>
<tr>
<td>Erica Goetze</td>
<td>UH</td>
<td>NSF</td>
<td>Temporal stability of copepod populations at Station ALOHA</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>Ken Johnson, Steve Riser &amp; Dana Swift</td>
<td>UW/MBARI</td>
<td>NSF</td>
<td>APEX profiling instrument development &amp; deployments</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. 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-BEACH web page (hahana.soest.hawaii.edu/hot/hot_jgosf).
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 an 10 km 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. 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.

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-BEACH 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 2015. Starting point of deployment indicated by “S”. [Right panels] CTD cast locations during each HOT cruise in 2015. 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: Due to ship problems and heavy weather conditions during HOT-276, the ship returned to port without deploying any bouys or conducting any casts at Station ALOHA.
Figure 1.2: Due to rough seas and high winds during HOT-278, the sediment trap array was not deployed.
Figure 1.2: Rough sea conditions during the recovery of the sediment trap array caused the traps to spill and fill with surface seawater. All samples were lost.
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 is 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 2015.

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 provide 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. The objective of this project 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 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/recovery cruise reports (Plueddemann et al., 2006; Whelan et al., 2007, 2008, 2010; Santiago-Mandujano et al., 2009). 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 in order 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 profilers (ADCP).

The subsurface instrumentation is located to resolve the temporal variations of shear and stratification in the upper pycnocline to support 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 clearly important to the stratification, as salt-stratified barrier layers are observed at HOT and in the region, so we use Sea-Bird SeaCATs and MicroCATs with vertical separation ranging from 5-20 m to measure temperature and salinity. We use an RDI ADCP to obtain current profiles across the entrainment zone and another in the mixed layer. Both ADCPs are in an upward-looking configuration, one is at 125 m, using 4 m bins, and the other is a 47.5 m using 2 m bins. To provide near-surface velocity (where the ADCP estimates are less reliable) we deploy two Vector Measuring Current Meters (VMCMs). The nominal mooring design is a balance between resolving extremes versus typical annual cycling of the mixed layer. A pair of Sea-Bird SeaCATs (SBE-16) have been included in the mooring a few meters from the anchor starting with 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 2015

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Depth Range (m)</th>
<th>Analytical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Continuous Measurements</td>
<td></td>
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</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>
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<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>Nitrate (NO₃)</td>
<td>0-1000</td>
<td>Satlantic’s In Situ Ultraviolet Spectrophotometer (ISUS) with discrete nitrate calibration</td>
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<td>II. Water Column Chemical Measurements</td>
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<td>Salinity</td>
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<td>Guildline AutoSal using Wormley seawater standard</td>
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<td>Oxygen</td>
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<td>Dissolved Inorganic Carbon</td>
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<td>Total Alkalinity</td>
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### III. Biomass Measurements

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<tr>
<th>Chlorophyll (a) and Pheopigments</th>
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<th>Fluorometric analysis using 10-AU</th>
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<td>Pigments</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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<th>Primary Production</th>
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<td>Carbon, Nitrogen, Phosphorus, Silica</td>
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### V. Currents

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

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<th>Incident Irradiance</th>
<th>Surface</th>
<th>LI-COR LI-1000 &amp; Satlantic HyperOCR Hyperspectral Radiometer</th>
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<td>Upwelling Radiance and Downwelling Irradiance</td>
<td>0-200</td>
<td>Satlantic Profiler II with HyperOCR Hyperspectral Radiometers &amp; WET Labs ECO-BB2F Triplet</td>
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<td>Absorption and Beam Attenuation</td>
<td>0-200</td>
<td>WET Labs AC-S connected to Sea-Bird CTD package</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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</table>
VII. Bow Intake System

| Temperature | 3 | Sea-Bird remote temperature sensor |
| Conductivity (Salinity) | 3 | Sea-Bird temperature and conductivity sensors inside the thermosalinograph package, with discrete salinity samples calibration |
| Fluorometry (Chloropigment) | 3 | Fluorometric analysis using 10-AU |

VIII. Moored Instruments

| Sequencing Sediment Traps | 2800, 4000 | Parflux MK7-21 |
| Physical Oceanographic Mooring | 0-155 | WHOTS |

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 27th full year of the HOT Program (January-December 2015). During this period, eleven HOT cruises were conducted using the University of Hawaii research vessels R/V Ka'imikai-O-Kanaloa (KOK) and R/V Kilo Moana (Table 1.4). In addition, selected data collected with the WHOTS-11 mooring instruments (July 2014 through July 2015), and during the mooring recovery cruise (WHOTS-12) on board the NOAA ship Hi'ialakai are presented here (see Plueddemann et al., 2013).

University of Hawaii shipboard technical assistance personnel assisted a total field scientific crew of 62 HOT staff, students and visiting scientists (Table 1.5) in our 2015 field work.

Table 1.4: Chronology of 2015 HOT Cruises

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<th>Return</th>
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<td>WHOTS-12</td>
<td>Hi'ialakai</td>
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Table 1.5: 2015 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 2015 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 and oxygen sensors and fluorometer described in Tupas et al. (1995). CTD underwater unit #09P43777-0850 (referred to as #0850) was used during all cruises in 2015. During HOT-270, this CTD malfunctioned and OTG’s SeaBird 9/11-Plus CTD (SN 568) was used for most casts. In addition, a Satlantic ISUS V3 (#097) measuring dissolved nitrate has been installed in one of the CTD channels since HOT-181.

CTD casts were made at Stations Kahe and ALOHA during each 2015 cruise except HOT-276 (no Station ALOHA casts) and HOT-279 (no Station Kahe cast). A CTD cast to 1000 m was made at Station Kahe during all the cruises HOT-269 to HOT-278. During HOT-276, this was the only cast conducted during the cruise due to rough weather and sea conditions at Station ALOHA.

At Station ALOHA, a burst of consecutive CTD casts to 1000 m is made over 36 hours to span the local inertial period and three semi-diurnal tidal cycles. The full 36-hour burst sampling period was not completed (to varying degrees) during HOT cruises 270, 276, 278, and 279. One WOCE standard cast within about 10 m of the bottom was made during each 2015 cruise (except HOT-276). A second deep cast was obtained at this Station during cruises 269-275 and 277.

A CTD cast to 2400 m was conducted at Station Kaena during six cruises during 2015 (HOT-271 to -275 and HOT-277).

CTD casts have been conducted during cruises near the WHOTS mooring since August 2004, for calibration of the moorings' sensors. CTD yo-yo casts to 200-m were conducted near the WHOTS-11 mooring (Station 50: 22 46.07’N, 157 53.95’W) during the 2015 cruises. Station 50 was occupied during HOT-269 through 273. Five yo-yo cycles were conducted during HOT-269 and HOT-271 to -273 but only four cycles were conducted during HOT-270. After cruise 273, the WHOTS mooring was recovered during the WHOTS-12 cruise and re-deployed to near the southeastern edge of the ALOHA circle (Station 52: 22 40.06’N, 157 56.96’W). Station 52 was occupied during HOT-274, -275, and -277. At least four yo-yo cycles were conducted during these three cruises (five cycles during HOT-274 and -277; fifth cycle of HOT-277 to 500-m). CTD yo-yo casts were also conducted near the mooring during the WHOTS-12
cruise before recovering the WHOTS-11 mooring and after deployment of the WHOTS-12 mooring (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 as 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 2015 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 is moving upward or when its acceleration exceeds 0.5 m s\(^{-2}\) in magnitude. Cruises 271-274, 278, and 279, were conducted under relatively rough conditions. The CTD acceleration cutoff value had to be increased to between 0.55 and 0.60 m s\(^{-2}\) for some of the casts to relax the data rejection criteria and avoid eliminating an excessive number of points. For HOT-271, -272, and -274, the acceleration cutoff had to be altered for around one-third or more of the casts.

The data were additionally screened by comparing the temperature and conductivity sensor pairs. These differences permitted 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. For HOT-270, a different set of sensors from the UH Ocean Technical Group had to be used part-way through the cruise after our primary and secondary CTDs failed; and on HOT-277, the secondary sensor had to be replaced during the cruise.

Temperature is reported in 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 and Nitrate are reported in \(\mu\)mol kg\(^{-1}\). Chloropigment (Fluorescence) is reported in \(\mu\)g/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 lab 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 at the time that 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 Paroscientific Model 760 pressure gauge equipped with a 10,000-PSI transducer. This instrument was purchased in March 1988, and was originally
calibrated against a primary standard. Subsequent recalibrations have been performed every 2.5 years on average either at the Northwest Regional Calibration Center, at the Scripps Institute of Oceanography or at Fluke Electronics (DH Instruments Division). The latest calibrations were conducted at the Scripps Institute of Oceanography in April 1999, May 2001, May 2003, and July 2005; and at Fluke in July 2009 and November 2012. The standard stopped working soon after the January 2014 bench tests, and was replaced by a new Digiquartz portable standard from Paroscientific SN 136923 in May 2016. There was no other standard available to conduct bench tests during the February 2014 to April 2016 period.

### 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 to 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 #101430 (CTD #0850) and #75434 (CTD #91361) are shown in Table 2.1. Pressure tests were not conducted between February 2014 and April 2016 because the transfer standard malfunctioned and could not be repaired.

Pressure transducer #101430 was used during all 2015 cruises, except during the HOT-270 cruise in which CTD #568 (which belongs to the UH Ocean Technical Group) with pressure sensor #75662 was used during some of the casts. Pressure transducer #75434 has not been used since HOT-212 (July 2009), therefore there is no record of the on-deck pressures to compare with our calibration's 0-dbar offset in 2015.

A 0.16 dbar correction was applied to the pressure offset at 0 dbar during data collection for all 2015 cruises that used sensor #101430, and -1.9337 dbar correction for the casts during HOT-270 that used sensor #75662 (however, a more accurate offset was later determined for the time that the CTD first enters the water on each cast). On-deck CTD pressures are regularly recorded during cruises at the beginning and at the end of each CTD cast, the mean of these pressures throughout each cruise are plotted in Figure 2.1 (the 0.16 dbar offset correction applied to casts has been removed in this plot to make it comparable with the data in Table 2.1).

The mean before-cast pressure by the end of 2015 (-0.30 dbar) is about 0.10 dbar higher than the mean 0 dbar offset from the August 2016 calibration (-0.40 dbar, Table 2.1a). The cause of this difference is because the sensor may have drifted during 2016, and also because prior to the pressure tests, the CTD is powered on 24 hours for full stabilization; while the on-deck pressures are recorded only about 10 min after the CTD is powered on. Pressure stabilization tests conducted in our lab have shown that our CTD pressure sensors change by up to 0.8 dbar during the first 10 minutes after applying power to the CTD, and the pressure continues to change a few tenths of a decibar until reaching full stabilization a few hours later.

Table 2.1b indicates that the 0-dbar pressure for sensor #75434 has decreased as compared to the January 2014 calibration.

The maximum difference of between before-cast and an after-cast on-deck pressure for sensor #101430 for all deep casts during 2015 cruises that used this sensor (Figure 2.1) was 0.10
dbar, slightly larger than the mean hysteresis measured in the lab in August 2016 (0.05 dbar, Table 2.1a). The hysteresis measured during the August 2016 bench test for sensor #75434 was 0.05 dbar (Table 2.1b).

The 0-4500 dbar pressure offset and hysteresis from the bench tests have been within expected values and decreased for both sensors relative to the January 2014 test. A linear pressure dependent offset was applied during data collection for sensor #101430, to correct for the 0-4500 dbar span offset of about 1.44 dbar from the January 2014 bench test (Table 2.1a).

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

<table>
<thead>
<tr>
<th>Calibration Date</th>
<th>Offset @ 0 dbar</th>
<th>0-4500 dbar offset</th>
<th>Hysteresis</th>
</tr>
</thead>
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<tr>
<td>3 August 2016</td>
<td>-0.40</td>
<td>0.75</td>
<td>0.05</td>
</tr>
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<td>8 January 2014</td>
<td>-0.20</td>
<td>1.44</td>
<td>0.22</td>
</tr>
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<td>1.39</td>
<td>0.14</td>
</tr>
<tr>
<td>10 January 2013</td>
<td>-0.17</td>
<td>1.31</td>
<td>0.13</td>
</tr>
<tr>
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<td>-0.10</td>
<td>1.15</td>
<td>0.09</td>
</tr>
<tr>
<td>8 February 2012</td>
<td>0.00</td>
<td>1.19</td>
<td>0.06</td>
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<tr>
<td>12 August 2011</td>
<td>0.04</td>
<td>1.32</td>
<td>0.05</td>
</tr>
<tr>
<td>20 January 2011</td>
<td>0.15</td>
<td>1.20</td>
<td>0.10</td>
</tr>
<tr>
<td>12 August 2010</td>
<td>0.20</td>
<td>1.20</td>
<td>0.15</td>
</tr>
<tr>
<td>8 January 2010</td>
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<td>1.30</td>
<td>0.16</td>
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<td>9 September 2009</td>
<td>0.21</td>
<td>1.30</td>
<td>0.13</td>
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<tr>
<td>7 January 2009</td>
<td>0.28</td>
<td>1.10</td>
<td>0.10</td>
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<tr>
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<td>0.31</td>
<td>1.20</td>
<td>0.09</td>
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<tr>
<td>24 July 2007</td>
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<td>1.10</td>
<td>0.10</td>
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<td>28 February 2007</td>
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<td>0.08</td>
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### Table 2.1b: CTD Pressure Calibrations against transfer standard. Units are decibars.

<table>
<thead>
<tr>
<th>Calibration Date</th>
<th>Offset @ 0 dbar</th>
<th>0-4500 dbar offset</th>
<th>Hysteresis</th>
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<td>Sea-Bird SBE-911 Plus #91361 / Pressure Transducer #75434</td>
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<td>0.05</td>
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<td>0.12</td>
<td>0.1</td>
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<tr>
<td>13 January 2000</td>
<td>0.1</td>
<td>0.13</td>
<td>0.08</td>
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<tr>
<td>24 June 1999</td>
<td>-0.03</td>
<td>0.20</td>
<td>0.1</td>
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Figure 2.1: Median value of on-deck pressure measured with the CTD pressure sensor #101430, before (circles) and after (crosses) each cast for HOT cruises 269 and 271-279. Error bars are one standard deviation from the mean. Cruise numbers are shown in the upper X-axis.

2.1.2.2 Temperature

Five Sea-Bird SBE-3-Plus temperature transducers #1416, #5519, #4448, #5554, and #5443 were used during 2015 HOT and WHOTS cruises. These and our other two transducers #2454 and #2907 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., 2016, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006, 2005, 2004, 2002, Santiago-Mandujano et al., 2000, Tupas et al., 1993, 1994a, 1995, 1997, 1998, 1999, Karl et al. 1996). Sensors #5543 and #5554 belong to the UH Ocean Technical Group (OTG), and were used together with their CTD during HOT-270 after our primary and secondary CTDs failed. Calibration coefficients obtained at Sea-Bird for these sensors after 2014 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):

\[
temperature = \frac{1}{a + b[ln(f_0/f)] + c[ln^2(f_0/f)] + d[ln^3(f_0/f)]} - 273.15
\] (1)
Table 2.2: Calibration coefficients for Sea-Bird temperature sensors. RMS residuals from
calibration give an indication of quality of the calibration. Sensors #2045, #1392, #2078, and
#1496 were used in the thermosalinograph (Section 2.2).
SN
1416
1416
1416
1416
1416

Date
yymmdd
160105
150825
150506
150113
140813

f0

a

b

6233.06
6233.09
6233.17
6233.14
6233.21

3.68120938E-03
3.68120902E-03
3.68120933E-03
3.68120901E-03
3.68120888E-03

6.01714722E-04
6.01712026E-04
6.01724125E-04
6.01721914E-04
6.01718871E-04

1.45807194E-05
1.45924394E-05
1.46410358E-05
1.46130045E-05
1.46016425E-05

1.76968310E-06
1.78807067E-06
1.83412886E-06
1.79876432E-06
1.79065084E-06

RMS
(m°C)
0.32
0.34
0.33
0.33
0.31

4448
4448
4448
4448
4448

160105
150825
150506
150113
140813

3075.48
3075.49
3075.51
3075.53
3075.51

3.68121360E-03
3.68121331E-03
3.68121365E-03
3.68121342E-03
3.68121319E-03

5.92708705E-04
5.92714112E-04
5.92724345E-04
5.92718437E-04
5.92718134E-04

1.49710448E-05
1.49704214E-05
1.50322385E-05
1.49896931E-05
1.49952537E-05

1.15170296E-06
1.14823694E-06
1.21457029E-06
1.17796377E-06
1.18286027E-06

0.09
0.05
0.07
0.08
0.06

5519
5519
5519
5519
5519

160105
150825
150506
150113
140813

3004.16
3004.18
3004.20
3004.20
3004.21

3.68121326E-03
3.68121296E-03
3.68121321E-03
3.68121292E-03
3.68121282E-03

5.90834294E-04
5.90838908E-04
5.90844566E-04
5.90854272E-04
5.90839636E-04

1.49323160E-05
1.49317642E-05
1.49656863E-05
1.49832378E-05
1.49411530E-05

1.58182153E-06
1.57599740E-06
1.61241668E-06
1.61883495E-06
1.58494597E-06

0.06
0.04
0.05
0.05
0.04

2454
2454
2454
2454
2454

160105
150825
150506
150113
140821

2885.05
2885.06
2885.07
2885.06
2885.09

3.68121178e-03
3.68121174e-03
3.68121170e-03
3.68121181e-03
3.68121173e-03

6.02162724e-04
6.02180453e-04
6.02182696e-04
6.02185910e-04
6.02190988e-04

1.66558517e-05
1.67209455e-05
1.67255053e-05
1.67286718e-05
1.67399832e-05

2.27363533e-06
2.34118775e-06
2.33903899e-06
2.33597982e-06
2.35255960e-06

0.06
0.05
0.10
0.05
0.05

2907
2907
2907
2907
2907

160105
150825
150506
150113
140821

3035.45
3035.47
3035.46
3035.47
3035.56

3.68121326e-03
3.68121296e-03
3.68121358e-03
3.68121334e-03
3.68121208e-03

5.99778319e-04
5.99782722e-04
5.99805617e-04
5.99791424e-04
5.99759978e-04

1.59692619e-05
1.59500134e-05
1.60420820e-05
1.59703569e-05
1.58551138e-05

2.17185402e-06
2.14666114e-06
2.22392831e-06
2.15850847e-06
2.06555676e-06

0.13
0.09
0.17
0.10
0.03

5554
5554
5554

150917
131212
120512

1000.00
1000.00
1000.00

4.32240288E-03 6.26422302E-04 1.70571879E-05
4.32292109E-03 6.27432777E-04 1.77257648E-05
4.32323759E-03 6.28133201E-04 1.82354202E-05

7.82722723E-07
9.19977483E-07
1.04065945E-06

0.36
0.11
0.07

5443
5443
5443
5443

160105
140409
130104
111124

1000.00
1000.00
1000.00
1000.00

4.29767381E-03
4.29773913E-03
4.29782219E-03
4.29784276E-03

6.24057668E-04
6.24111554E-04
6.24290851E-04
6.24401555E-04

1.85976224E-05
1.86195750E-05
1.87569931E-05
1.88838799E-05

1.24912288E-06
1.25082259E-06
1.28528392E-06
1.32507055E-06

0.05
0.05
0.06
0.07

1496
1496
1496
1496
1496
1496
1496
1496
1496

140213
120216
110120
060929
050903
030531
020406
010803
010118

5951.50
5951.38
5951.41
5951.22
5951.32
5951.07
5950.97
5965.19
5964.13

3.68121487e-03
3.68121493e-03
3.68121339e-03
3.68121525e-03
3.68121888e-03
3.68121159e-03
3.68121326e-03
3.67981425e-03
3.67991358e-03

5.89910179e-04
5.89926200e-04
5.89928429e-04
5.89916144e-04
5.89924752e-04
5.89910979e-04
5.89924007e-04
5.89878647e-04
5.89881380e-04

1.46589217e-05
1.47028321e-05
1.47169039e-05
1.46429025e-05
1.46445105e-05
1.46402233e-05
1.46555677e-05
1.46556176e-05
1.46683349e-05

2.91632422e-06
2.93391128e-06
2.94616539e-06
2.88351075e-06
2.88655316e-06
2.89014609e-06
2.90029383e-06
2.88953261e-06
2.91772668e-06

0.20
0.19
0.19
0.20
0.17
0.22
0.21
0.18
0.20

27

c

d


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 least squares fit to the 0-30 °C average of each calibration during the year. The maximum drift correction in 2015 was less than 1.6 x 10^{-3} °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 2015 cruises. The temperature differences between sensor pairs were calculated for each cast to evaluate the quality of the data, and to 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 2015 cruises, showing temperature differences within expected values. The mean temperature difference as a function of pressure was typically less than 1 x 10^{-3} °C, with a standard deviation of less than 0.5 x 10^{-3} °C below 500 dbar. The largest variability was observed in the thermocline, with standard deviation values of up to 5 x 10^{-3} °C.

**Sensor #1416**

This sensor has maintained a stable drift for a long time, and was used during all the 2015 cruises. The calibrations from February 2009 through January 2016 yielded a sensor drift of 3.72 x 10^{-6} °C day\(^{-1}\), with an intercept of -3.6 x 10^{-4} °C and a RMS residual of 3.6 x 10^{-4} °C, which was used to obtain the drift correction for cruises HOT-269 through HOT-279, and WHOTS-12. When corrected for linear drift to 12 July 2015 (the mid-date when the sensor was used), the 1 August 2015 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 2015). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 0.7 m°C, and were applied to the data (Table 2.3).

**Sensor #5519**

This sensor was used during all the 2015 cruises except HOT-269. The calibrations from February 2012 through January 2015 indicated that there was a change in its calibration drift after the November 2013 calibration. The calibrations between February 2014 and January 2015 yielded a sensor drift of 1.97 x 10^{-6} °C day\(^{-1}\), with an intercept of -1.4 x 10^{-4} °C and a RMS residual of 1.4 x 10^{-4} °C, which was used to obtain the drift correction for cruises HOT-270 through HOT-279, and WHOTS-12. When corrected for linear drift to 12 July 2015 (the mid-date when the sensor was used), the January 2016 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 2015). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 0.6 m°C, and were applied to the data (Table 2.3).

**Sensor #4448**

This sensor was used during HOT-269. The calibrations from February 2012 through January 2016 yielded a sensor drift of 7.9 x 10^{-7} °C day\(^{-1}\), with an intercept of -2.1 x 10^{-4} °C and a RMS residual of 1.9 x 10^{-4} °C, which was used to obtain the drift correction for cruise HOT-269. When corrected for linear drift to 25 February 2015 (the mid-date when the sensor was used), the May 2015 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 25 February 2015). Drift corrections were
obtained using this calibration as a baseline. The resulting drift corrections for the cruise is shown in Table 2.3.

Sensor #5554

This sensor was used during some of the HOT-270 casts. The calibrations shown in Table 2.2 yielded a sensor drift of $3.22 \times 10^{-6}$ °C day$^{-1}$, with an intercept of $9.9 \times 10^{-4}$ °C and a RMS residual of $7.0 \times 10^{-4}$ °C, which was used to obtain the drift correction for cruise HOT-270 casts. When corrected for linear drift to 27 March 2015 (the mid-date when the sensor was used), the December 2013 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 27 March 2015). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for the cruise is shown in Table 2.3.

Sensor #5443

This sensor was used during some of the HOT-270 casts. The calibrations shown in Table 2.2 yielded a sensor drift of $2.18 \times 10^{-6}$ °C day$^{-1}$, with an intercept of $6.2 \times 10^{-4}$ °C and a RMS residual of $4.2 \times 10^{-4}$ °C, which was used to obtain the drift correction for cruise HOT-270 casts. When corrected for linear drift to 27 March 2015 (the mid-date when the sensor was used), the April 2014 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 27 March 2015). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for the cruise is shown in Table 2.3.

Sensor #2454

This sensor was not used during 2015. The calibrations from September 2008 through January 2015 indicated a slight change in drift rate in August 2013. The calibrations after this date yielded a sensor drift of $1.83 \times 10^{-6}$ °C day$^{-1}$ for this sensor, with an intercept of $-2.5 \times 10^{-4}$ °C and a RMS residual of $1.9 \times 10^{-4}$ °C.

Sensor #2907

This sensor was not used during 2015. The calibrations from September 2012 through January 2016 were used to calculate the sensor drift of $1.53 \times 10^{-6}$ °C day$^{-1}$ with an intercept of $-5.7 \times 10^{-4}$ °C and a RMS residual of $4.9 \times 10^{-4}$ °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-269</td>
<td>1416</td>
<td>-0.000673</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-269</td>
<td>4448</td>
<td>-0.000055</td>
<td>2959</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>1416</td>
<td>-0.000554</td>
<td>3984</td>
<td>0.028</td>
<td>S1C1, S2C1-2</td>
</tr>
<tr>
<td>HOT-270</td>
<td>5519</td>
<td>-0.000557</td>
<td>2959</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>5554</td>
<td>0.001511</td>
<td>4074</td>
<td>0.020</td>
<td>S2C3-10, S50C1</td>
</tr>
<tr>
<td>HOT-270</td>
<td>5443</td>
<td>0.000767</td>
<td>3876</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-271</td>
<td>1416</td>
<td>-0.000465</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-271</td>
<td>5519</td>
<td>-0.000510</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-272</td>
<td>1416</td>
<td>-0.000346</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-272</td>
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<td>-0.000446</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-273</td>
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<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-273</td>
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<td>-0.000393</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>WHOTS-12</td>
<td>1416</td>
<td>-0.000160</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>WHOTS-12</td>
<td>5519</td>
<td>-0.000348</td>
<td>2959</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-274</td>
<td>1416</td>
<td>-0.000134</td>
<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-274</td>
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<td>-0.000334</td>
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<tr>
<td>HOT-275</td>
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<td>3984</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-275</td>
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<td>2959</td>
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</tr>
<tr>
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<td>0.000123</td>
<td>3984</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
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<td>-0.000197</td>
<td>2959</td>
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<td></td>
</tr>
<tr>
<td>HOT-277</td>
<td>1416</td>
<td>0.000186</td>
<td>3984</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-277</td>
<td>5519</td>
<td>-0.000164</td>
<td>2959</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-277</td>
<td>5519</td>
<td>-0.000164</td>
<td>2218</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>HOT-278</td>
<td>1416</td>
<td>0.000301</td>
<td>3162</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-278</td>
<td>5519</td>
<td>-0.000103</td>
<td>2218</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-279</td>
<td>1416</td>
<td>0.000394</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-279</td>
<td>5519</td>
<td>-0.000053</td>
<td>2218</td>
<td>0.037</td>
<td></td>
</tr>
</tbody>
</table>

### 2.1.2.3 Conductivity

Six conductivity sensors were used during the 2015 cruises, #3162, #2218, #2959, #3984, #4074 and #3876. Sensor #2959 was sent to Sea-Bird for evaluation in November 2015 after failing during the first deep cast of HOT-277. The instrument’s cell was found cracked by the center electrode on the cell, and the cell was replaced. The history of the sensors is well documented in previous HOT Data Reports (Fujieki et al., 2016, 2015, 2014, 2013, 2012, 2011, 2010, 2008, 2007, 2006, 2005, 2004, 2002, Santiago-Mandujano et al., 2000, Tupas et al., 1993, 1994a, 1995, 1997, 1998, 1999, Karl et al. 1996). Sensors #4074 and #3876 belong to the OTG, and were used together with their CTD during HOT-270 after our primary and secondary CTDs failed. The dual sensor configurations are shown in Table 2.3. As mentioned earlier, only the data from the most reliable sensor (and its corresponding temperature sensor pair, as shown in Table 2.3) are reported here.
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. Prior to 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 $\alpha$ 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-269 through -279, the standard deviation cutoff values for screening of bottle salinity samples were: 0.0034 (0-150 dbar), 0.0050 (151-500 dbar), 0.0019 (501-1050 dbar), and 0.0010 (1051-5000 dbar).

The conductivity calibration coefficients ($b0$, $b1$, $b2$) derived from the least squares fit ($\Delta C = b0 + b1C + b2C^2$) 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 as described in Tupas et al. (1993) to allow for drift during each cruise or for sudden offsets due to fouling (Table 2.5). Note that a change of $1 \times 10^{-4}$ 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 as for the temperature sensors (Section 2.1.2.2). The range of variability as a function of pressure was about $\pm 1 \times 10^{-4}$ Siemens m$^{-1}$, with a standard deviation of less than $0.5 \times 10^{-4}$ 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 up to $5 \times 10^{-4}$ Siemens m$^{-1}$ between 50 and 300 dbar.
Table 2.4: Conductivity calibration coefficients

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>b0</th>
<th>b1</th>
<th>b2</th>
</tr>
</thead>
<tbody>
<tr>
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<td>3984</td>
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<td>0.000035</td>
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</tr>
<tr>
<td>HOT-269</td>
<td>2959</td>
<td>0.000296</td>
<td>-0.000056</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>3984</td>
<td>-0.000584</td>
<td>-0.000113</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>2959</td>
<td>-0.000079</td>
<td>0.000039</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>4074</td>
<td>0.000315</td>
<td>-0.000021</td>
<td></td>
</tr>
<tr>
<td>HOT-270</td>
<td>3876</td>
<td>0.000052</td>
<td>0.000183</td>
<td></td>
</tr>
<tr>
<td>HOT-271</td>
<td>3984</td>
<td>-0.000211</td>
<td>0.000039</td>
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</tr>
<tr>
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<td>2959</td>
<td>0.000099</td>
<td>-0.000009</td>
<td></td>
</tr>
<tr>
<td>HOT-272</td>
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</tr>
<tr>
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</tr>
<tr>
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<tr>
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</tbody>
</table>
Table 2.5: Individual cast conductivity corrections (units are Siemens m\(^{-1}\))

<table>
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<th>Station</th>
<th>Cast</th>
<th>C Correction</th>
</tr>
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<td>0.000060</td>
</tr>
<tr>
<td>HOT-274</td>
<td>2</td>
<td>16</td>
<td>0.000040</td>
</tr>
<tr>
<td>HOT-274</td>
<td>6</td>
<td>1</td>
<td>0.000030</td>
</tr>
<tr>
<td>HOT-275</td>
<td>2</td>
<td>2</td>
<td>0.000060</td>
</tr>
<tr>
<td>HOT-275</td>
<td>2</td>
<td>15</td>
<td>-0.000040</td>
</tr>
<tr>
<td>HOT-275</td>
<td>6</td>
<td>1</td>
<td>-0.000120</td>
</tr>
<tr>
<td>HOT-277</td>
<td>2</td>
<td>2</td>
<td>0.000030</td>
</tr>
<tr>
<td>HOT-277</td>
<td>2</td>
<td>15</td>
<td>-0.000070</td>
</tr>
<tr>
<td>HOT-278</td>
<td>2</td>
<td>1</td>
<td>0.000100</td>
</tr>
</tbody>
</table>
Table 2.6: CTD-Bottle salinity comparison for each cruise

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>0-4800 dbar</th>
<th>500-4800 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>St. dev</td>
<td>Mean</td>
</tr>
<tr>
<td>HOT-269</td>
<td>3984</td>
<td>-0.0002</td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0016</td>
<td>-0.0003</td>
</tr>
<tr>
<td>HOT-269</td>
<td>2959</td>
<td>-0.0006</td>
<td>0.0015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0015</td>
<td>-0.0001</td>
</tr>
<tr>
<td>HOT-270</td>
<td>3984</td>
<td>0.0001</td>
<td>0.0011</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0011</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-270</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0012</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0012</td>
<td>0.0000</td>
</tr>
<tr>
<td>HOT-271</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0017</td>
<td>-0.0003</td>
</tr>
<tr>
<td>HOT-271</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0018</td>
<td>0.0002</td>
</tr>
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<td>HOT-272</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0016</td>
</tr>
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<td></td>
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<td>0.0016</td>
<td>-0.0002</td>
</tr>
<tr>
<td>HOT-272</td>
<td>2959</td>
<td>-0.0001</td>
<td>0.0015</td>
</tr>
<tr>
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<td>0.0000</td>
</tr>
<tr>
<td>HOT-273</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0016</td>
<td>-0.0003</td>
</tr>
<tr>
<td>HOT-273</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0015</td>
<td>0.0000</td>
</tr>
<tr>
<td>WHOTS-12</td>
<td>3984</td>
<td>0.0000</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0020</td>
<td>-0.0004</td>
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<tr>
<td>WHOTS-12</td>
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<td>0.0000</td>
<td>0.0013</td>
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<td></td>
<td></td>
<td>0.0013</td>
<td>-0.0006</td>
</tr>
<tr>
<td>HOT-274</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0017</td>
<td>-0.0005</td>
</tr>
<tr>
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<td>2959</td>
<td>-0.0001</td>
<td>0.0018</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0018</td>
<td>-0.0001</td>
</tr>
<tr>
<td>HOT-275</td>
<td>3984</td>
<td>0.0000</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0020</td>
<td>-0.0004</td>
</tr>
<tr>
<td>HOT-275</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0020</td>
<td>0.0000</td>
</tr>
<tr>
<td>HOT-276</td>
<td>3984</td>
<td>0.0000</td>
<td>0.0019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0019</td>
<td>-0.0009</td>
</tr>
<tr>
<td>HOT-276</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0019</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0019</td>
<td>-0.0004</td>
</tr>
<tr>
<td>HOT-277</td>
<td>3984</td>
<td>0.0000</td>
<td>0.0022</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0022</td>
<td>-0.0006</td>
</tr>
<tr>
<td>HOT-277</td>
<td>2959</td>
<td>0.0000</td>
<td>0.0020</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0020</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-278</td>
<td>3162</td>
<td>0.0000</td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0016</td>
<td>-0.0001</td>
</tr>
<tr>
<td>HOT-278</td>
<td>2218</td>
<td>-0.0001</td>
<td>0.0015</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0015</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-279</td>
<td>3162</td>
<td>0.0000</td>
<td>0.0010</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0010</td>
<td>-0.0001</td>
</tr>
<tr>
<td>HOT-279</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0016</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.0016</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
Figure 2.2: Difference between calibrated CTD salinities and bottle salinities for each cruise and all casts at Station ALOHA in 2015.
2.1.2.4 Oxygen

During the 2015 cruises six Sea-Bird SBE-43 oxygen sensors were used: #43262, #43982, #43918, #431601, #43019 and #43224. The history of these sensors is documented in previous HOT Data Reports (Fujieki et al., 2016, 2015, 2014, 2013, 2012, 2010, 2008, 2007, 2006, 2005).

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 consists of fitting 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 together for each cruise to find the best set of parameters 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 procedure for the Sea-Bird SBE-43 sensors is documented in Santiago-Mandujano et al. (2001). No oxygen samples were collected during cruise WHOTS-12 which used the same sensors used during HOT-274, therefore HOT-274 coefficients were used to calibrate WHOTS-12 oxygen data.

Table 2.7 shows the mean and standard deviation for the calibrated CTD oxygen minus water sample residuals for each cruise. 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>0 to 1500 dbar</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOT-269</td>
<td>43918</td>
<td>0.00</td>
<td>0.43</td>
</tr>
<tr>
<td>HOT-270</td>
<td>43918</td>
<td>0.00</td>
<td>0.70</td>
</tr>
<tr>
<td>HOT-271</td>
<td>43918</td>
<td>0.00</td>
<td>0.67</td>
</tr>
<tr>
<td>HOT-272</td>
<td>43918</td>
<td>0.00</td>
<td>0.45</td>
</tr>
<tr>
<td>HOT-273</td>
<td>43918</td>
<td>0.00</td>
<td>0.62</td>
</tr>
<tr>
<td>HOT-274</td>
<td>43918</td>
<td>0.00</td>
<td>0.55</td>
</tr>
<tr>
<td>HOT-275</td>
<td>43982</td>
<td>0.01</td>
<td>0.77</td>
</tr>
<tr>
<td>HOT-276</td>
<td>43982</td>
<td>0.00</td>
<td>0.54</td>
</tr>
<tr>
<td>HOT-277</td>
<td>43262</td>
<td>0.01</td>
<td>0.68</td>
</tr>
<tr>
<td>HOT-278</td>
<td>43982</td>
<td>0.00</td>
<td>0.67</td>
</tr>
</tbody>
</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 4800 dbar Mean</th>
<th>SD</th>
<th>500 to 4800 dbar Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-269</td>
<td>43918</td>
<td>0.00</td>
<td>0.89</td>
<td>-0.01</td>
<td>0.58</td>
</tr>
<tr>
<td>HOT-270</td>
<td>43918</td>
<td>0.00</td>
<td>0.53</td>
<td>0.03</td>
<td>0.49</td>
</tr>
<tr>
<td>HOT-271</td>
<td>43918</td>
<td>-0.02</td>
<td>0.88</td>
<td>-0.02</td>
<td>0.66</td>
</tr>
<tr>
<td>HOT-272</td>
<td>43918</td>
<td>0.01</td>
<td>0.76</td>
<td>0.00</td>
<td>0.70</td>
</tr>
<tr>
<td>HOT-273</td>
<td>43918</td>
<td>0.00</td>
<td>0.77</td>
<td>-0.07</td>
<td>0.40</td>
</tr>
<tr>
<td>HOT-274</td>
<td>43918</td>
<td>0.01</td>
<td>0.61</td>
<td>0.00</td>
<td>0.55</td>
</tr>
<tr>
<td>HOT-275</td>
<td>43982</td>
<td>-0.17</td>
<td>0.73</td>
<td>-0.30</td>
<td>0.74</td>
</tr>
<tr>
<td>HOT-277</td>
<td>43262</td>
<td>0.00</td>
<td>0.78</td>
<td>-0.15</td>
<td>0.73</td>
</tr>
<tr>
<td>HOT-278</td>
<td>43982</td>
<td>-0.02</td>
<td>0.71</td>
<td>-0.07</td>
<td>0.57</td>
</tr>
<tr>
<td>HOT-279</td>
<td>43982</td>
<td>0.00</td>
<td>0.70</td>
<td>0.00</td>
<td>0.79</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, \( V_{chl} = b \cdot V_{fluor} + a \), was used to convert all fluorescence data to chloropigment.

2.1.2.6 Nitrate

Real-time nitrate concentrations were measured with a Satlantic ISUS V3 (#097). The ISUS is a chemical-free, solid-state sensor that uses ultraviolet absorption spectroscopy to measure continuous nitrate concentrations. Data was collected from as many 1000m casts as possible. Instrument drift was corrected via calibration with bottle inorganic [nitrate+nitrite] analyzed using a six-channel Bran Luebbe Autoanalyzer III as described in Section 2.5.4.1. Only samples below 200m were used in the calibration where nitrite values at Station ALOHA are considered negligible. A linear relationship of the form, \( V_{nitrate} = b \cdot V_{ISUS} + a \), was used. Data was logged internally and also collected using the Sea-Bird CTD system. Internally recorded profiles were latter downloaded after the cruise. CTD values were preferentially reported unless the data was considered bad. A common reason for bad data was a poor seal when connecting the Analog output cable to the CTD. Internally recorded data was then substituted.
2.1.3 Discrete salinity

Salinity samples were collected, stored and analyzed as described in Tupas et al. (1993). IAPSO samples were measured to standardize the salinometer, and samples from a large batch of “secondary standard” (substandard) seawater were measured after every 24-48 bottle samples of each cruise to detect drift in the salinometer. Standard deviations of the secondary standard measurements were less than ± 0.0010 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 1000 m from Station ALOHA. Two batches of secondary standard seawater were used during 2015. Batch #58 was created on June 4th, 2014. Batch #59 was created on December 11th, 2014.

Prior to making each substandard batch, all Substandard making materials and supplies were cleaned thoroughly. The plastic carboy used to collect the Substandard seawater on the cruise was bleached before collection. The glass carboys were washed with liquinox, rinsed with water, hexane, rinsed with water again, and then rinsed with 99% alcohol before drying. The glass rods were rinsed with hexane and 99% alcohol. The carboy (and glass rod) was rinsed with the collected Substandard water 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 water.

Table 2.8: Precision of salinity measurements using secondary lab standards

<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-269</td>
<td>34.4664±0.0002</td>
<td>19</td>
<td>58</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-270</td>
<td>34.4663±0.0002</td>
<td>18</td>
<td>58</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-271</td>
<td>34.4666±0.0004</td>
<td>24</td>
<td>58</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-272</td>
<td>34.4678±0.0004</td>
<td>24</td>
<td>58</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-273</td>
<td>34.4673±0.0003</td>
<td>16</td>
<td>58</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-274</td>
<td>34.4665±0.0010</td>
<td>30</td>
<td>59</td>
<td>P156</td>
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<tr>
<td>HOT-275</td>
<td>34.4651±0.0003</td>
<td>16</td>
<td>59</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-276</td>
<td>34.4643±0.0003</td>
<td>4</td>
<td>59</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-277</td>
<td>34.4643±0.0003</td>
<td>22</td>
<td>59</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-278</td>
<td>34.4644±0.0002</td>
<td>16</td>
<td>59</td>
<td>P156</td>
</tr>
<tr>
<td>HOT-279</td>
<td>34.4641±0.0003</td>
<td>17</td>
<td>59</td>
<td>P156</td>
</tr>
</tbody>
</table>

2.2 Thermosalinograph

2.2.1 Data Acquisition

Continuous near-surface salinity and temperature data were collected during every 2015 HOT cruise (HOT-269 through HOT-279) using Sea-Bird thermosalinograph and temperature sensors aboard the R/V *Kilo Moana* and R/V *Ka‘imikai-O-Kanaloa*. The details of each thermosalinograph system varied from ship to ship, but 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. Salinity of the seawater was then calculated using the internal temperature and conductivity as well as the internal pressure of the pump. The 2015 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 to the thermosalinograph. Thermosalinograph data from each cruise were also compared with the CTD temperature and conductivity data collected at roughly the same time and from near the same depth as the seawater supply intake for a final data quality control.

Table 2.9: 2015 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/SBE-3</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>External T</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>SBE-45</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Internal T and C</strong></td>
</tr>
<tr>
<td>HOT-269</td>
<td>KOK</td>
<td>1496</td>
</tr>
<tr>
<td>HOT-270</td>
<td>KOK</td>
<td>1496</td>
</tr>
<tr>
<td>HOT-271</td>
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<td>0396</td>
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<tr>
<td>HOT-272</td>
<td>KM</td>
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</tr>
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<tr>
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<tr>
<td>HOT-275</td>
<td>KOK</td>
<td>2078</td>
</tr>
<tr>
<td>HOT-276</td>
<td>KOK</td>
<td>2078</td>
</tr>
<tr>
<td>HOT-277</td>
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</tr>
<tr>
<td>HOT-278</td>
<td>KM</td>
<td>0150</td>
</tr>
<tr>
<td>HOT-279</td>
<td>KOK</td>
<td>2078</td>
</tr>
</tbody>
</table>

KOK = R/V Ka’imikai-O-Kanaloa  
KM = R/V Kilo Moana

The thermosalinograph system aboard the R/V Kilo Moana consisted of a SBE-38 external temperature sensor which was located in the bow-thruster chamber in the starboard bow close to the seawater intake. The depth of the intake was 8 meters below the surface, and the internal pressure of the pump was approximately 6 dbar. A SBE-45 Seacat thermosalinograph measuring conductivity and temperature (internal) was located in the IMET lab at the port bow of the ship.

Data from the SBE-38 remote and SBE-45 thermosalinograph sensor were acquired every second. These data were processed and calibrated against bottled salinity samples. Final data for 2015 from cruises in the R/V Kilo Moana are derived from the SBE-45 thermosalinograph at 1 second intervals, and 10 second intervals from cruises aboard R/V Ka’imikai-O-Kanaloa.
During cruises on board the R/V *Kilo Moana* before HOT-271, the external temperature sensor was situated just aft of the seawater intake pump and the resultant water temperatures were consistently higher than values obtained with the CTD at the same depth, apparently due to heating from the pump. This was corrected before HOT-271 by repositioning the intake pump, and the temperatures recorded by the external temperature sensor are no longer affected by the pump.

The thermosalinograph system aboard the R/V *Ka’imikai-O-Kanaloa* consisted of an internal SBE-21 Seacat thermosalinograph unit along with a SBE-3 external temperature sensor installed in a sea-chest at the bow of the ship. The depth of the seawater intake was approximately 3 meters below the surface, and the internal pressure of the pump was ~15 dbar. Data were acquired every 10 seconds.

### 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 ([Tables 2.2](#), and [Table 2.10](#)).

Sensor #1496 was used on board the R/V *Ka’imikai-O-Kanaloa* during HOT-269 and -270 cruises. Calibrations in [Table 2.2](#) were used to calculate a sensor drift of -1.1 x 10^{-6} °C day^{-1}. Temperatures were calculated with the 13 February 2014 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than 5.0 x 10^{-4} °C and inconsequential.

Sensor #2045 was used on board the R/V *Ka’imikai-O-Kanaloa* during HOT-275 to -277. Calibrations in [Table 2.2](#) were used to calculate a sensor drift of -5.6 x 10^{-8} °C day^{-1}. Temperatures were calculated with the 30 December 2014 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than 0.2 x 10^{-4} °C and inconsequential.

Sensor #1392 was used on board the R/V *Ka’imikai-O-Kanaloa* during HOT-269 and -270 cruises. Calibrations in [Table 2.2](#) were used to calculate a sensor drift of 4.0 x 10^{-7} °C day^{-1}. Temperatures were calculated with the 12 February 2014 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than 2.0 x 10^{-4} °C and inconsequential.

Sensor #2078 was used on board the R/V *Ka’imikai-O-Kanaloa* during HOT-275 to -277. Calibrations in [Table 2.2](#) were used to calculate a sensor drift of -2.2 x 10^{-7} °C day^{-1}. Temperatures were calculated with the 8 January 2015 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than 0.7 x 10^{-4} °C and inconsequential.
Internal temperature sensors #218 and #267 are an SBE-45 model, and external temperature sensors #0150, and #0396 are an SBE-38 model. These sensors use the following equation to convert the instrument output (n) to temperature (in °C):

\[
\text{temperature} = \frac{1}{a_0 + a_1 \ln(n) + a_2 \ln^2(n) + a_3 \ln^3(n)} - 273.15
\]

A temperature drift rate of \(7.49 \times 10^{-9}\) °C day\(^{-1}\) was determined for internal temperature sensor #218 using the calibrations in Table 2.10. Temperatures were calculated with the 7 November 2013 baseline calibration for cruises HOT-271 and -272. Drift corrections were not applied to the data for this sensor, as they were less than 0.04 \(\times 10^{-4}\) °C.

A temperature drift rate of \(-5.4 \times 10^{-7}\) °C day\(^{-1}\) was determined for internal temperature sensor #267 using the calibrations in Table 2.10. Temperatures were calculated with the 15 May 2015 baseline calibration for the HOT-273, -274 and -278 cruise data. Drift corrections were not applied to the data for this sensor, as they were less than 1 \(\times 10^{-4}\) °C.

A temperature drift rate of \(1.20 \times 10^{-7}\) °C day\(^{-1}\) was determined for external temperature sensor #0150 using the calibrations in Table 2.10. Temperatures were calculated with the 13 January 2015 baseline calibration for the HOT-273, -274 and -278 cruise data. Drift corrections were not applied to the data for this sensor, as they were less than 0.4 \(\times 10^{-4}\) °C.

A temperature drift rate of \(1.06 \times 10^{-7}\) °C day\(^{-1}\) was determined for external temperature sensor #0396 using the calibrations in Table 2.10. Temperatures were calculated with the 10 April 2014 baseline calibration for cruises HOT-271 and -272. Drift corrections were not applied to the data for this sensor, as they were less than 0.5 \(\times 10^{-4}\) °C.
Table 2.10: Calibration coefficients for Sea-Bird temperature sensors SBE-45 and SBE-38. RMS residuals from calibration give an indication of the quality of calibration.

<table>
<thead>
<tr>
<th>SN</th>
<th>Date</th>
<th>a0</th>
<th>a1</th>
<th>a2</th>
<th>a3</th>
<th>RMS (m°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>218</td>
<td>131107</td>
<td>1.9711400e-05</td>
<td>2.7842800e-04</td>
<td>-2.66793200e-06</td>
<td>1.5945800e-07</td>
<td>0.10</td>
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<tr>
<td>218</td>
<td>121121</td>
<td>-3.27708300e-05</td>
<td>2.8118940e-04</td>
<td>-2.86199800e-06</td>
<td>1.6399000e-07</td>
<td>0.10</td>
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<tr>
<td>218</td>
<td>110504</td>
<td>-5.23851400e-05</td>
<td>2.85819500e-04</td>
<td>-3.22659100e-06</td>
<td>1.73569700e-07</td>
<td>0.07</td>
</tr>
<tr>
<td>218</td>
<td>100306</td>
<td>-1.67452600e-05</td>
<td>2.77748600e-04</td>
<td>-2.61747100e-06</td>
<td>1.58246600e-07</td>
<td>0.07</td>
</tr>
<tr>
<td>218</td>
<td>090203</td>
<td>-2.78285300e-05</td>
<td>2.80350600e-04</td>
<td>-2.82034800e-06</td>
<td>1.63498900e-07</td>
<td>0.05</td>
</tr>
<tr>
<td>218</td>
<td>090124</td>
<td>-4.32989500e-06</td>
<td>2.75136300e-04</td>
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<td>218</td>
<td>071120</td>
<td>-4.33471600e-05</td>
<td>2.83622300e-04</td>
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<td>1.68729900e-07</td>
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<td>267</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>
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<tr>
<td>267</td>
<td>140410</td>
<td>-2.36766100e-04</td>
<td>2.87190900e-04</td>
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<td>2.78775700e-04</td>
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<tr>
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<td>2.11735100e-07</td>
<td>0.03</td>
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<tr>
<td>150</td>
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<td>-1.82930400e-04</td>
<td>3.09166900e-04</td>
<td>-4.70791200e-06</td>
<td>2.09073200e-07</td>
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<td>2.04003700e-07</td>
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<tr>
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<td>150</td>
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<td>-1.83124100e-04</td>
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<td>2.09063900e-07</td>
<td>0.03</td>
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<td>150</td>
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<td>3.10492500e-04</td>
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<td>0.03</td>
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<td>2.07947600e-07</td>
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<td>396</td>
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<td>1.52735200e-07</td>
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</tr>
</tbody>
</table>

2.2.2.1.2 Conductivity

Three different conductivity sensors were used to collect thermosalinograph data for the 2015 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 Siemens m⁻¹ for conductivity. There were 7 gross errors detected in temperature during HOT-275, 1 gross error detected in temperature during
HOT-276, 3 gross errors detected in temperature during HOT-277, 6 gross errors detected in temperature during HOT-278, and 23 gross errors detected in temperature during HOT-279. No other gross errors were detected in temperature or conductivity during the other 2015 HOT cruises. A typical cruise aboard R/V Kilo Moana contained approximately 325,000 – 335,000 1-sec interval data points. The cruise aboard R/V Ka'imikai-O-Kanaloa contained 21,866 10-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 5-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 5-point median filter were immediately replaced by the median. Threshold values of 0.3 °C for temperature and 0.1 Siemens m\(^{-1}\) 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 was manually inspected to further flag suspect or bad data.

The number of thermosalinograph data points flagged as suspicious or bad per cruise ranged from 0 – 70 aboard the R/V Kilo Moana, while 133 points were flagged during the cruise aboard R/V Ka'imikai-O-Kanaloa. Occasionally, 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, while the shallow intake of R/V Ka'imikai-O-Kanaloa allows for frequent spikes in the data due to these bubbles. Other flagged data were a result of 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 2015 cruises which often resulted in sections of data being flagged and are summarized below:

- **HOT-270**: Both CTDs failed after the 3\(^{rd}\) cast; replacement CTD pick-up was required. Conductivity data during transit was subject to more spikes than typically observed. Spikes also observed during transit for array recovery.

- **HOT-275**: A drift of 6.0 \(\times\) 10\(^{-4}\) S/m in thermosalinograph conductivity from the CTD was observed throughout the cruise. Additionally, 4 casts were removed as temperature outliers, and 3 bottles were removed as conductivity outliers.

- **HOT-276**: Winch boom tensionometer failure onboard KOK; thermosalinograph data was separated into two separate cruise transects. Conductivity data during transit back to Station ALOHA was subject to more spikes than typically observed.

- **HOT-277**: A drift of 1.0 \(\times\) 10\(^{-3}\) S/m in thermosalinograph conductivity from the CTD was observed throughout the cruise.
• **HOT-278:** The external temperature sensor record appeared to be very noisy until approx. 09:57 AM on November 14\textsuperscript{th}, 2015, after which the variability improved. External temperature prior to this point were flagged as suspect. Additionally, a drift of $8.0 \times 10^{-4}$ S/m in thermosalinograph conductivity was observed from the measured bottle samples.

• **HOT-279:** The system was shut off unexpectedly during the return from Station ALOHA on December 11\textsuperscript{th}, 2015 at 04:08 AM. All thermosalinograph samples taken after this point were excluded from analysis.

An estimate of the noise in thermosalinograph data was performed to evaluate quality. A 101-point running mean (about 17 min. at 10 sec 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 estimated to avoid large residuals resulting in sections of large variability. Noise estimates were obtained for cruises HOT-269 through HOT-279 (Table 2.11).

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Salinity Noise (psu)</th>
<th>Temperature Noise (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-269</td>
<td>0.0038</td>
<td>0.0005</td>
</tr>
<tr>
<td>HOT-270</td>
<td>0.0053</td>
<td>0.0009</td>
</tr>
<tr>
<td>HOT-271</td>
<td>0.0036</td>
<td>0.0008</td>
</tr>
<tr>
<td>HOT-272</td>
<td>0.0055</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-273</td>
<td>0.0052</td>
<td>0.0006</td>
</tr>
<tr>
<td>HOT-274</td>
<td>0.0045</td>
<td>0.0006</td>
</tr>
<tr>
<td>HOT-275</td>
<td>0.0045</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-276</td>
<td>0.0074</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-277</td>
<td>0.0048</td>
<td>0.0024</td>
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<tr>
<td>HOT-278</td>
<td>0.0118</td>
<td>0.0008</td>
</tr>
<tr>
<td>HOT-279</td>
<td>0.0043</td>
<td>0.0007</td>
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</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 the R/V *Kilo Moana* and R/V *Ka'imikai-O-Kanaloa* 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 thermsalinograph conductivity separately for all the 2015 HOT cruises. The correction of the thermsalinograph conductivities was obtained from this fit. Salinity was calculated using these corrected conductivities, thermsalinograph temperatures, and the pressure of the pump. The mean values for the salinity bottle minus final calibrated thermsalinograph were less than ±9 \times 10^{-6} for all cruises, with standard deviations shown in Table 2.12.

Table 2.12: Bottle-Thermsalinograph Salinity Comparison

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>Standard Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-269</td>
<td>1392</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-270</td>
<td>1392</td>
<td>0.0004</td>
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<td>HOT-271</td>
<td>0218</td>
<td>0.0005</td>
</tr>
<tr>
<td>HOT-272</td>
<td>0218</td>
<td>0.0002</td>
</tr>
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<td>HOT-273</td>
<td>0267</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-274</td>
<td>0267</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-275</td>
<td>2045</td>
<td>0.0007</td>
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<tr>
<td>HOT-276</td>
<td>2045</td>
<td>0.0009</td>
</tr>
<tr>
<td>HOT-277</td>
<td>2045</td>
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<td>HOT-278</td>
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</tr>
<tr>
<td>HOT-279</td>
<td>0267</td>
<td>0.0005</td>
</tr>
</tbody>
</table>

2.2.2.4 Comparison with the CTD Data

The external temperature and the calibrated thermsalinograph salinity data collected during CTD casts were compared with the downcast CTD salinity from 8 dbar (R/V Kilo Moana cruises) and 4 dbar (R/V Ka’imikai-O-Kanaloa) as an additional quality control. This procedure was conducted in the same manner as previously reported HOT cruises. The thermsalinograph data were averaged using data sampled one minute after the acquisition time of the CTD sample.

Due to changes in the external temperature sensor plumbing on the R/V Kilo Moana, there is no longer a warming effect from the underway seawater pump (observed on all pervious cruises aboard R/V Kilo Moana), since the sensor is now placed before the pump (see Section 2.2.1). Mean thermsalinograph salinity difference with the CTD salinity were smaller than ±0.004 psu for all cruises. Mean temperature differences between the CTD and the external temperature sensor and the mean temperature differences between the CTD and the internal temperature sensor for HOT-276 have been neglected, as it was a shortened cruise.
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>
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</thead>
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<td>HOT-269</td>
<td>1496</td>
<td>0.0044</td>
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<td>-0.00256</td>
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<td>HOT-270</td>
<td>1496</td>
<td>-0.00132</td>
<td>1392</td>
<td>0.001059</td>
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<td>HOT-271</td>
<td>0396</td>
<td>-0.03297</td>
<td>218</td>
<td>0.000315</td>
</tr>
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<td>HOT-272</td>
<td>0396</td>
<td>-0.02901</td>
<td>218</td>
<td>0.000911</td>
</tr>
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<td>HOT-273</td>
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<td>-0.01283</td>
<td>267</td>
<td>-0.00056</td>
</tr>
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<td>-0.02091</td>
<td>267</td>
<td>-0.00354</td>
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<td>-</td>
<td>2045</td>
<td>-</td>
</tr>
<tr>
<td>HOT-277</td>
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<td>0.005197</td>
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<td>2078</td>
<td>-0.00795</td>
<td>2045</td>
<td>-0.00045</td>
</tr>
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</table>

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 recorded at 5-min intervals from the anemometers on the R/V Kilo Moana (21 m height), and the R/V Ka’imikai-O-Kanaloa (18 m height) were also available.

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 3.4 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 2015 were measured using shipboard Acoustic Doppler Current Profilers (ADCP) on board R/V Kilo Moana and R/V Kaʻimikai-O-Kanaloa.

ADCP data on board R/V Kilo Moana and Kaʻimikai-O-Kanaloa 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 at a later date.

The R/V Kilo Moana is equipped with two ADCP systems. An RD Instruments Ocean Surveyor 38 is located on the starboard side of the ship 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 is able to profile to 1200 m in broadband mode (OS38BB) with a bin size of 12 m averaging ensembles every 5 minutes. In narrow band 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 4 m and averaging ensembles every 2 minutes. Heading information is taken from the gyro compass and corrected using a TSS POS/MV 320 (an integrated inertial and GPS system). 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 Kaʻimikai-O-Kanaloa was used during HOT-269, -270, -275-277, and -279. The ship was equipped with a WorkHorse 300 that was enabled to sample to depths of 150 m and bin sizes of 4 m. Ensembles were taken every 2 minutes.

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

ADCP data collected using OS38BB, OS38NB, and WH300 onboard R/V Kilo Moana and Kaʻimikai-O-Kanaloa during HOT-269 through HOT-279 were processed without any reported incidents, apart from HOT-279 where ADCP data were broken into cruise parts A and B: part A had no data. HOT-276 only recorded data up to Station Kahe, due to returning to port after the weight cast. ADCP data do not seem to have been logged on the northbound leg of HOT-269, with the exception of just a few data points.
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/hot_jgofs.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 2015.

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. (1993). 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.

During HOT-269, the CTD squirt boom failed when power to the boom hydraulics was left on for too long during a near bottom CTD cast. The CTD package was suspended above the water outboard of the ship during the ~2.5 hour delay. This caused the anomalously high sample temperature values (Δ oxygen > 4.5 deg C) shown in Figure 2.3 (upper panel). Since it made (on average) only a 0.04 µmol kg⁻¹ difference in the calculation of oxygen (Figure 2.3, lower panel), and since the average mean SD of triplicate samples of oxygen is ~ 0.25 µmol kg⁻¹ (Table 2.14), we determined it's well within the sampling error and thus decided to not make any corrections.
Figure 2.3: [Upper panel] Difference between sample temperature at the time of sample collection and potential temperature calculated from *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 *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 2015 was 0.14 %, which was calculated by averaging the mean CV of N-triplicate samples on each cruise. Oxygen concentrations measured over the 27 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 27 years of the HOT program.

Table 2.14: Precision of Winkler titration method during 2015

<table>
<thead>
<tr>
<th>HOT</th>
<th>Dissolved O₂</th>
<th>Mean CV (%)</th>
<th>Mean SD (µmol kg⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>269</td>
<td></td>
<td>0.23</td>
<td>0.394</td>
<td>8</td>
</tr>
<tr>
<td>270</td>
<td></td>
<td>0.15</td>
<td>0.271</td>
<td>8</td>
</tr>
<tr>
<td>271</td>
<td></td>
<td>0.11</td>
<td>0.182</td>
<td>8</td>
</tr>
<tr>
<td>272</td>
<td></td>
<td>0.12</td>
<td>0.215</td>
<td>8</td>
</tr>
<tr>
<td>273</td>
<td></td>
<td>0.10</td>
<td>0.194</td>
<td>8</td>
</tr>
<tr>
<td>274</td>
<td></td>
<td>0.14</td>
<td>0.240</td>
<td>8</td>
</tr>
<tr>
<td>275</td>
<td></td>
<td>0.13</td>
<td>0.228</td>
<td>8</td>
</tr>
<tr>
<td>276</td>
<td></td>
<td>0.12</td>
<td>0.257</td>
<td>2</td>
</tr>
<tr>
<td>277</td>
<td></td>
<td>0.18</td>
<td>0.307</td>
<td>8</td>
</tr>
<tr>
<td>278</td>
<td></td>
<td>0.12</td>
<td>0.226</td>
<td>8</td>
</tr>
<tr>
<td>279</td>
<td></td>
<td>0.12</td>
<td>0.219</td>
<td>7</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td><strong>0.14</strong></td>
<td><strong>0.249</strong></td>
<td><strong>11</strong></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 2015 was 0.02 % (Table 2.15). It was calculated by averaging the mean CV of N-duplicate samples on each cruise. Total alkalinity (Talk) was determined using the modified Gran titration method as described in Tupas et al. (1997). The pooled annual CV of the Talk analyses during 2015 was 0.04 % (Table 2.15).

Table 2.15: Precision of DIC and Total Alkalinity analyses during 2015

<table>
<thead>
<tr>
<th>HOT</th>
<th>DIC</th>
<th>Talk</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (μmol kg⁻¹)</td>
<td>N</td>
</tr>
<tr>
<td>269</td>
<td>0.00</td>
<td>0.106</td>
<td>3</td>
</tr>
<tr>
<td>270</td>
<td>0.01</td>
<td>0.288</td>
<td>3</td>
</tr>
<tr>
<td>271</td>
<td>0.04</td>
<td>0.884</td>
<td>3</td>
</tr>
<tr>
<td>272</td>
<td>0.02</td>
<td>0.364</td>
<td>2</td>
</tr>
<tr>
<td>273</td>
<td>0.01</td>
<td>0.137</td>
<td>3</td>
</tr>
<tr>
<td>274</td>
<td>0.01</td>
<td>0.240</td>
<td>3</td>
</tr>
<tr>
<td>275</td>
<td>0.03</td>
<td>0.660</td>
<td>3</td>
</tr>
<tr>
<td>277</td>
<td>0.01</td>
<td>0.177</td>
<td>3</td>
</tr>
<tr>
<td>278</td>
<td>0.00</td>
<td>0.094</td>
<td>3</td>
</tr>
<tr>
<td>279</td>
<td>0.03</td>
<td>0.594</td>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.354</td>
<td>10</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=103) was -0.22 ± 1.21 µmol kg⁻¹.

Figure 2.5: Total alkalinity (Talk) measured difference from certified reference materials (CRMs). The mean (± stdev, n=266) was -2.13 ± 4.06 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
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 2015 was 0.018 (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 2015

<table>
<thead>
<tr>
<th>HOT</th>
<th>pH Mean CV (%)</th>
<th>pH Mean SD (Total@25°C)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>269</td>
<td>0.011</td>
<td>0.0009</td>
<td>4</td>
</tr>
<tr>
<td>270</td>
<td>0.012</td>
<td>0.0009</td>
<td>4</td>
</tr>
<tr>
<td>271</td>
<td>0.022</td>
<td>0.0017</td>
<td>4</td>
</tr>
<tr>
<td>272</td>
<td>0.013</td>
<td>0.0011</td>
<td>3</td>
</tr>
<tr>
<td>273</td>
<td>0.020</td>
<td>0.0015</td>
<td>4</td>
</tr>
<tr>
<td>274</td>
<td>0.045</td>
<td>0.0037</td>
<td>3</td>
</tr>
<tr>
<td>275</td>
<td>0.022</td>
<td>0.0018</td>
<td>4</td>
</tr>
<tr>
<td>277</td>
<td>0.006</td>
<td>0.0005</td>
<td>3</td>
</tr>
<tr>
<td>278</td>
<td>0.020</td>
<td>0.0016</td>
<td>4</td>
</tr>
<tr>
<td>279</td>
<td>0.013</td>
<td>0.0010</td>
<td>3</td>
</tr>
<tr>
<td>Mean</td>
<td>0.018</td>
<td>0.0015</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 2.6: pH measured at 4500 decibars at Station ALOHA. The mean (± stdev, n=58) was 7.581 ± 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 2015 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 27 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 2015

<table>
<thead>
<tr>
<th>HOT</th>
<th>SRP Mean CV (%)</th>
<th>SRP Mean SD (µM)</th>
<th>N</th>
<th>[Nitrate + Nitrite] Mean CV (%)</th>
<th>[Nitrate + Nitrite] Mean SD (µM)</th>
<th>N</th>
<th>Silicate Mean CV (%)</th>
<th>Silicate Mean SD (µM)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>269</td>
<td>0.41</td>
<td>0.011</td>
<td>4</td>
<td>0.13</td>
<td>0.051</td>
<td>4</td>
<td>0.83</td>
<td>1.264</td>
<td>6</td>
</tr>
<tr>
<td>270</td>
<td>0.24</td>
<td>0.007</td>
<td>6</td>
<td>0.47</td>
<td>0.060</td>
<td>7</td>
<td>1.14</td>
<td>1.190</td>
<td>6</td>
</tr>
<tr>
<td>271</td>
<td>0.17</td>
<td>0.005</td>
<td>6</td>
<td>0.11</td>
<td>0.043</td>
<td>7</td>
<td>0.79</td>
<td>0.735</td>
<td>6</td>
</tr>
<tr>
<td>272</td>
<td>0.44</td>
<td>0.012</td>
<td>5</td>
<td>0.60</td>
<td>0.085</td>
<td>6</td>
<td>0.23</td>
<td>0.351</td>
<td>6</td>
</tr>
<tr>
<td>273</td>
<td>0.34</td>
<td>0.009</td>
<td>6</td>
<td>0.32</td>
<td>0.051</td>
<td>7</td>
<td>0.18</td>
<td>0.248</td>
<td>6</td>
</tr>
<tr>
<td>274</td>
<td>0.12</td>
<td>0.003</td>
<td>6</td>
<td>0.61</td>
<td>0.058</td>
<td>7</td>
<td>0.82</td>
<td>0.260</td>
<td>7</td>
</tr>
<tr>
<td>275</td>
<td>0.20</td>
<td>0.006</td>
<td>5</td>
<td>0.27</td>
<td>0.051</td>
<td>7</td>
<td>0.57</td>
<td>0.468</td>
<td>7</td>
</tr>
<tr>
<td>277</td>
<td>0.31</td>
<td>0.008</td>
<td>6</td>
<td>0.64</td>
<td>0.058</td>
<td>7</td>
<td>1.08</td>
<td>1.245</td>
<td>6</td>
</tr>
<tr>
<td>278</td>
<td>0.22</td>
<td>0.006</td>
<td>6</td>
<td>0.57</td>
<td>0.078</td>
<td>7</td>
<td>0.15</td>
<td>0.158</td>
<td>7</td>
</tr>
<tr>
<td>279</td>
<td>0.51</td>
<td>0.014</td>
<td>6</td>
<td>0.39</td>
<td>0.081</td>
<td>7</td>
<td>0.20</td>
<td>0.187</td>
<td>7</td>
</tr>
</tbody>
</table>

Mean 0.30 0.008 10 0.41 0.062 10 0.60 0.611 10
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: KH₂PO₄ (1 mM), KNO₃ (1 mM) and Na₂SiF₆ (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 NO₃, 2 µM for PO₄, 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 ~1.8 is acceptable. The mean (± stdev, n=302) was 1.897 ± 0.030 µM.

Figure 2.10: OSIL - 100 µM stock in DIW, diluted in LNSW to be 2 µM. The mean (± stdev, n=647) was 1.986 ± 0.022 µM.
Figure 2.11: Wako - 40.0 µM in NaCl, measured directly. The mean (± stdev, n=266) was 39.805 ± 0.328 µM.

Figure 2.12: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 40 µM. The mean (± stdev, n=567) was 39.795 ± 0.358 µM.
Figure 2.13: Wako - 100.0 µM in NaCl, measured directly. The mean (± stdev, n=311) was 100.501 ± 0.705 µM.

Figure 2.14: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 100 µM. The mean (± stdev, n=546) was 100.299 ± 0.559 µM.
Figure 2.15: Wako - 100.0 µM in NaCl, measured directly. The mean (± stdev, n=333) was 100.528 ± 0.710 µM.

Figure 2.16: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 100 µM. The mean (± stdev, n=545) was 100.404 ± 0.633 µM.
Special Cases

In the case of Phosphorus, 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.

![WAKO Potassium Nitrate Quality Control Chart](image)

Figure 2.17: The mean (± stdev, n=71) was 4.05 ± 0.50 nmol L⁻¹.
Figure 2.18: The mean (± stdev, n=76) was 15.75 ± 0.96 nmol L⁻¹.

Figure 2.19: The mean (± stdev, n=71) was 157.05 ± 4.29 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=92) was 1.0 ± 2.3 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 2010 from duplicate TOC analyses are given in Table 2.18.

Table 2.18: Precision of Total Organic Carbon analyses of replicate samples during 2010

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (µM)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>219</td>
<td>3.9</td>
<td>1.567</td>
<td>4</td>
</tr>
<tr>
<td>220</td>
<td>1.4</td>
<td>0.550</td>
<td>4</td>
</tr>
<tr>
<td>221</td>
<td>4.1</td>
<td>1.695</td>
<td>4</td>
</tr>
<tr>
<td>222</td>
<td>2.6</td>
<td>1.030</td>
<td>4</td>
</tr>
<tr>
<td>223</td>
<td>2.1</td>
<td>0.842</td>
<td>4</td>
</tr>
<tr>
<td>224</td>
<td>3.4</td>
<td>1.313</td>
<td>4</td>
</tr>
<tr>
<td>225</td>
<td>5.8</td>
<td>2.273</td>
<td>4</td>
</tr>
<tr>
<td>226</td>
<td>7.2</td>
<td>2.894</td>
<td>4</td>
</tr>
<tr>
<td>227</td>
<td>2.0</td>
<td>0.830</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>3.6</td>
<td>1.444</td>
<td>9</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.
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 O₂ 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 2015 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 2.19: Field variability of Particulate carbon and nitrogen analyses during 2015

<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>269</td>
<td>6.6</td>
<td>1.499</td>
</tr>
<tr>
<td>270</td>
<td>5.7</td>
<td>1.085</td>
</tr>
<tr>
<td>271</td>
<td>9.3</td>
<td>2.655</td>
</tr>
<tr>
<td>272</td>
<td>9.8</td>
<td>2.924</td>
</tr>
<tr>
<td>273</td>
<td>33.0</td>
<td>6.739</td>
</tr>
<tr>
<td>274</td>
<td>2.6</td>
<td>0.771</td>
</tr>
<tr>
<td>275</td>
<td>4.3</td>
<td>0.940</td>
</tr>
<tr>
<td>277</td>
<td>10.0</td>
<td>2.751</td>
</tr>
<tr>
<td>278</td>
<td>3.6</td>
<td>0.693</td>
</tr>
<tr>
<td>279</td>
<td>5.9</td>
<td>0.909</td>
</tr>
<tr>
<td>Mean</td>
<td>9.1</td>
<td>2.097</td>
</tr>
</tbody>
</table>

Figure 2.22a: PC/PN ratios obtained using acetanilide check standard. The mean (± stdev, n=201) was 8.05 ± 0.23.
2.5.6.2 Particulate Phosphorus

Samples for elemental analyses of Particulate phosphorus (PPO₄) were prefiltered through 202 μm 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 2015 are presented in Table 2.20.
Table 2.20: Field variability of Particulate phosphorus analyses during 2015

<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>269</td>
<td>3.0</td>
<td>0.014</td>
<td>2</td>
</tr>
<tr>
<td>270</td>
<td>4.8</td>
<td>0.021</td>
<td>2</td>
</tr>
<tr>
<td>271</td>
<td>3.6</td>
<td>0.014</td>
<td>1</td>
</tr>
<tr>
<td>272</td>
<td>16.4</td>
<td>0.071</td>
<td>1</td>
</tr>
<tr>
<td>273</td>
<td>13.3</td>
<td>0.035</td>
<td>1</td>
</tr>
<tr>
<td>274</td>
<td>15.3</td>
<td>0.057</td>
<td>1</td>
</tr>
<tr>
<td>275</td>
<td>20.8</td>
<td>0.103</td>
<td>2</td>
</tr>
<tr>
<td>277</td>
<td>37.4</td>
<td>0.163</td>
<td>1</td>
</tr>
<tr>
<td>278</td>
<td>12.3</td>
<td>0.078</td>
<td>2</td>
</tr>
<tr>
<td>279</td>
<td>2.6</td>
<td>0.014</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>13.0</td>
<td>0.057</td>
<td>10</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.

Figure 2.23: Recovery of PPO₄ as a percentage of the expected amount. The mean (± stdev, n=102) was 91.61 ± 2.16.
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 PPO₄ 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 PPO₄ 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 PPO₄ 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 2.24c: 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 (DeMaster, 1981). The average field variability between duplicate analyses during 2015 are presented in Table 2.21.

Table 2.21: Field variability of Particulate biogenic silica analyses during 2015

<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>269</td>
<td>10.3</td>
<td>1.718</td>
<td>2</td>
</tr>
<tr>
<td>270</td>
<td>47.2</td>
<td>5.993</td>
<td>2</td>
</tr>
<tr>
<td>271</td>
<td>33.3</td>
<td>7.022</td>
<td>2</td>
</tr>
<tr>
<td>272</td>
<td>14.2</td>
<td>2.298</td>
<td>2</td>
</tr>
<tr>
<td>273</td>
<td>10.8</td>
<td>1.499</td>
<td>2</td>
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<tr>
<td>274</td>
<td>16.5</td>
<td>3.348</td>
<td>2</td>
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<td>275</td>
<td>18.7</td>
<td>4.052</td>
<td>2</td>
</tr>
<tr>
<td>277</td>
<td>8.0</td>
<td>1.648</td>
<td>2</td>
</tr>
<tr>
<td>278</td>
<td>8.4</td>
<td>2.871</td>
<td>2</td>
</tr>
<tr>
<td>279</td>
<td>18.9</td>
<td>2.326</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>18.6</td>
<td>3.278</td>
<td>10</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 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). The average precisions during 2015 determined from triplicate analyses are presented in Table 2.22.

Table 2.22: Precision of Fluorometric Chlorophyll \( a \) and Pheopigment analyses during 2015

<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>269</td>
<td>10.2</td>
<td>0.013</td>
<td>6</td>
<td>6.8</td>
</tr>
<tr>
<td>270</td>
<td>5.7</td>
<td>0.007</td>
<td>6</td>
<td>8.8</td>
</tr>
<tr>
<td>271</td>
<td>2.6</td>
<td>0.005</td>
<td>6</td>
<td>4.0</td>
</tr>
<tr>
<td>272</td>
<td>2.5</td>
<td>0.003</td>
<td>6</td>
<td>5.1</td>
</tr>
<tr>
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<td>7.3</td>
<td>0.008</td>
<td>6</td>
<td>8.4</td>
</tr>
<tr>
<td>274</td>
<td>27.2</td>
<td>0.011</td>
<td>6</td>
<td>13.8</td>
</tr>
<tr>
<td>275</td>
<td>4.9</td>
<td>0.004</td>
<td>6</td>
<td>6.6</td>
</tr>
<tr>
<td>276</td>
<td>1.2</td>
<td>0.002</td>
<td>3</td>
<td>2.3</td>
</tr>
<tr>
<td>277</td>
<td>5.9</td>
<td>0.009</td>
<td>6</td>
<td>4.3</td>
</tr>
<tr>
<td>278</td>
<td>5.0</td>
<td>0.003</td>
<td>4</td>
<td>17.5</td>
</tr>
<tr>
<td>279</td>
<td>8.4</td>
<td>0.006</td>
<td>4</td>
<td>8.9</td>
</tr>
<tr>
<td>Mean</td>
<td>7.4</td>
<td>0.007</td>
<td>11</td>
<td>7.9</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 and retention times yielded by this method during 2015 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 2015.

Table 2.23: 2015 HPLC Pigment analysis Response factors and Retention times

<table>
<thead>
<tr>
<th>Pigment</th>
<th>RF&lt;sup&gt;a&lt;/sup&gt;</th>
<th>RT&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll c &amp; Mg 3,8D&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.245</td>
<td>NA</td>
</tr>
<tr>
<td>Peridinin</td>
<td>0.550</td>
<td>0.369</td>
</tr>
<tr>
<td>19'-Butanoyloxyfucoxanthin</td>
<td>0.375</td>
<td>0.398</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>0.380</td>
<td>0.435</td>
</tr>
<tr>
<td>19'-Hexanoyloxyfucoxanthin</td>
<td>0.378</td>
<td>0.474</td>
</tr>
<tr>
<td>Prasinoxanthin</td>
<td>0.420</td>
<td>0.533</td>
</tr>
<tr>
<td>Violaxanthin</td>
<td>0.280</td>
<td>0.565</td>
</tr>
<tr>
<td>Diadinoxanthin</td>
<td>0.289</td>
<td>0.638</td>
</tr>
<tr>
<td>Alloxanthin</td>
<td>0.286</td>
<td>0.711</td>
</tr>
<tr>
<td>Lutein</td>
<td>0.297</td>
<td>0.787</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>0.318</td>
<td>0.799</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll b</td>
<td>0.970</td>
<td>0.936</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll a</td>
<td>0.607</td>
<td>1.000</td>
</tr>
<tr>
<td>Divinyl Chlorophyll a</td>
<td>0.499</td>
<td>1.000</td>
</tr>
<tr>
<td>α-Carotene</td>
<td>0.266</td>
<td>1.178</td>
</tr>
<tr>
<td>β-Carotene</td>
<td>0.295</td>
<td>1.184</td>
</tr>
</tbody>
</table>

<sup>a</sup>RF - Response Factor (ng l<sup>-1</sup> pigment per unit absorbance peak area at 436 nm).
<sup>b</sup>RT - Retention Time (minutes, relative to chlorophyll a)
<sup>c</sup>Chlorophyll c = (c<sub>1</sub> + c<sub>2</sub> + c<sub>3</sub>), Mg 3,8D = Mg 3,8 divinyl pheoporphyrin a<sub>5</sub> 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 2015. 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’-triphosphate

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 2015 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 2015

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (ng l⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>269</td>
<td>15.8</td>
<td>2.195</td>
<td>8</td>
</tr>
<tr>
<td>270</td>
<td>15.4</td>
<td>1.466</td>
<td>9</td>
</tr>
<tr>
<td>271</td>
<td>29.4</td>
<td>4.698</td>
<td>9</td>
</tr>
<tr>
<td>272</td>
<td>33.0</td>
<td>4.480</td>
<td>9</td>
</tr>
<tr>
<td>273</td>
<td>12.1</td>
<td>2.485</td>
<td>9</td>
</tr>
<tr>
<td>274</td>
<td>28.0</td>
<td>3.266</td>
<td>9</td>
</tr>
<tr>
<td>275</td>
<td>22.2</td>
<td>4.728</td>
<td>8</td>
</tr>
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<td>277</td>
<td>8.0</td>
<td>1.408</td>
<td>8</td>
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<td>278</td>
<td>17.8</td>
<td>2.056</td>
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<td>279</td>
<td>14.9</td>
<td>3.965</td>
<td>7</td>
</tr>
<tr>
<td>Mean</td>
<td>19.7</td>
<td>3.075</td>
<td>10</td>
</tr>
</tbody>
</table>
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 2015, 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, P and Si as described in Section 2.5.6 above. Typically six traps are analyzed for PC and PN, three for PP, 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-1000 data logger and cosine collector. The instrument recorded data from the time the ship departed Snug Harbor 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 Inherent Optical Properties (IOPs): Absorption and Beam Attenuation

Profiles of absorption ($a(\lambda)$) and beam attenuation ($c(\lambda)$) were made using a WET Labs AC-9 & a WET Labs AC-S. The AC-9 simultaneously determined the spectral attenuation and spectral absorption of water at 412, 440, 488, 510, 532, 555, 650, 676 and 715nm. Each of these wavebands have bandpasses of approximately 10 nm. The sampling frequency is approximately 6 Hz. The AC-S is similar to the AC-9, except it provided 80+ wavelengths from 400-730nm with 4nm increments.

The AC-9 & AC-S were part of an instrument package that also included a Sea-Bird CTD, a WET Labs ECO-BBF2 Triplet (measuring Chlorophyll, CDOM & Phycoerythrin) and a Sequoia Laser In-Situ Scattering and Transmissometry (LISST-100X) instrument. The AC-9 & AC-S were oriented horizontally and lowered at a more-or-less constant speed of 10 m min$^{-1}$ to a bottom depth of approximately 200 m. At least 2 back-to-back profiles were normally taken, one using a 0.2 µm cartridge filter and one without. This allowed the spectral absorption and attenuation coefficient of both the total & dissolved matter to be determined. The particulate absorption and attenuation components were derived by subtracting the dissolved from the total component. The scattering of particles was estimated by subtracting the absorption from the attenuation particle spectrum.

2.7.4 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 \( V(D_i) \) in units of mL L\(^{-1}\) for 32 logarithmically spaced size classes with geometric mean diameters \( D_i \) 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 \( A(D_i) \) is then calculated from the volume size distribution \( \mu L L^{-1} \) by assuming spherical geometry: \( A(D_i) = \frac{3}{2} V(D_i) D_i^{-1} \). The mean particle size \( D_{AVG} \), the slope of the particle size distribution, and the total particle number (S 1.36mm - 230.14mm size classes) can then be calculated.

### 2.8 Microbial Community Structure

#### 2.8.1 Flow Cytometry

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.

Picoplankton 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.
Figure 2.27: *Prochlorococcus* measured at 5 decibars at Station ALOHA. The mean (± stdev, n=95) was $1.785 \times 10^5 \pm 0.534 \times 10^4$ # ml$^{-1}$.

Figure 2.28: *Prochlorococcus* measured at the DCM at Station ALOHA. The mean (± stdev, n=88) was $5.723 \times 10^4 \pm 0.156 \times 10^4$ # ml$^{-1}$.
2.8.2 Epi-Fluorescence Microscopy

Water samples of 50 ml (nanoplankton) and 300-500 ml (microplankton) are taken at each of 8 depths in the euphotic zone (surface to 175 m) from the same CTD profiles (and bottles) that sample the microbial community by HPLC pigments and flow cytometry. The 50-ml samples are preserved with 2-ml of 10% paraformaldehyde and stained with proflavin (0.33% w/v). The larger samples are preserved with 300 µl of alkaline Lugols solution followed by 10
ml of buffered formalin and 500 µl of sodium thiosulfate (modified protocol from Sherr and Sherr, 1993); and then stained with proflavin (0.33% w/v). Preserved samples are slowly (~5 psi) filtered onto either black 0.8-µm (50 ml) or 8.0-µm (300-500 ml) Nuclepore filters overlaying 20-µm Millipore backing filters to facilitate even cell distributions. During filtration, the samples are drawn down until approximately 1-2 ml remain in the filtration tower. Concentrated DAPI (50 mg ml⁻¹) is added and allowed to sit briefly before filtering the remainder of the sample until dry. Filters are mounted onto glass slides with immersion oil and cover slips. Prepared slides are placed in a dark box and kept frozen at -80°C until analysis.

Microscopical fields on the thawed slides are viewed and digitized at 630X (nanoplankton) or 200X (microplankton) with an automated Zeiss Axiovert 200M compound microscope equipped for epifluorescence microscopy and a 14 mega-pixel color CCD digital camera. For each slide, at least 25 random positions are imaged separately on four color channels with narrow band filters sets (green, blue, red and orange, respectively, for FITC, DAPI, chlorophyll a and phycoerythrin). The digital channel images are merged and analyzed using Image-Pro software. All object cells of >1.2 mm length are segmented from the background based upon green fluorescence (proflavin) threshold values, and cell length, width, feret min and max, roundness, radius, perimeter, and fluorescence measurements are quantified in list mode files for each color channel. Measurement calibration settings are applied to each image.

Autotrophic and heterotrophic cells are distinguished by the presence/absence of Chl a. Groups (including diatoms, dinoflagellates, prymnesiophytes and cyanobacteria) are enumerated manually and/or with neural network software based on characteristic sizes, shapes and fluorescence values. The biovolume of each cell is calculated using the formula of a prolate sphere: \( \pi \times \text{length} \times \text{width}^2 \times \frac{6}{1} \). Carbon per cell is calculated from biovolumes using carbon conversion factors from Eppley et al. (1970) for eukaryotic protists, and 240 fg C µm⁻³ for cyanobacteria (Worden et al., 2004).

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, Ottowa, 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 minillog 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. For this reason, caution is urged in comparing net collection in the largest (> 5 mm) size fraction before and after cruise 175.
(November 2005). 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-fractionated 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 -85°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-11 mooring was deployed at Station 50: 22 45.981’N, 157 53.964’W, during the WHOTS-11 cruise (July 15-23, 2014) on board the NOAA ship Hi‘ialakai, collecting data from 17 July 2014 to 14 July 2015, and was recovered during the WHOTS-12 cruise (July 9-16, 2015) on board the Hi‘ialakai. Details of the instrumentation (Figure 2.31), and deployment are in the project’s website (http://www.soest.hawaii.edu/whots). Briefly, a Surlyn foam surface buoy was 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 short wave and long wave radiation, and precipitation. Complete surface meteorological measurements were recorded every minute. Each ASIMET system also transmitted hourly averages of the surface meteorological variables via the Argos satellite system. Underwater instrumentation
included 16 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 and 155 m. The Microcats at 7, 45, 85, 105, 120, 135, and 155 m included a pressure sensor. In addition, two Microcats SBE-37 were installed below the buoy at 1.5 m, and two Seacats (SeaBird SBE-16) were installed near the bottom at 4671 m. 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 (NGVM) were deployed at 10 and 30 m respectively to measure current speed and direction.

Details about instruments deployed in the WHOTS mooring, as well as description of the mooring deployment/recovery cruises can be found in the cruise reports (Plueddemann et al., 2015, Santiago-Mandujano et al., 2015). 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 for 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. NGVM data are processed using the WHOI UOP software package (Prada, 1992).

All C-T instruments, as well as the ADCPs and the NGVMs from the WHOTS-11 mooring returned full records of high quality data, with two exceptions. The MicroCAT at 135 m was recovered with a broken connector and stopped recording data in November 2014; the ADCP at 47.5 m stopped recording data in May 2015. Details on the meteorological measurements are available at http://uop.whoi.edu/projects/WHOTS/whotsdetails.html.
Figure 2.31: WHOTS-11 mooring diagram
In addition to the mooring data, CTD casts were conducted during the July 9-16, 2015 WHOTS-12 cruise measuring pressure, temperature, conductivity and dissolved oxygen. Thirteen CTD casts were conducted at stations 50 (near the WHOTS-11 buoy) and 52 (near the WHOTS-12 buoy). Six CTD casts were conducted to obtain profiles for comparison with subsurface instruments on the WHOTS-11 mooring before recovery, and seven casts were conducted for comparison with the WHOTS-12 mooring after deployment. These were sited approximately 500 m from the buoys. The comparison casts consisted of 5 yo-yo cycles between 10 dbar and 200 dbar, except for the first cast at Station 50, which had only one cycle to 1460 dbar. Station numbers were assigned following the convention used during HOT cruises (see Table 2.25). Four salinity samples were taken during each cast to calibrate the CTD-conductivity sensor. The CTD data were collected with the same sensor configuration used during the HOT-274 cruise conducted a few days after (18-22 July, 2015), and the oxygen data were processed using the same oxygen calibration parameters (see Section 2.1.2.4).

Table 2.25: CTD stations occupied during the WHOTS-12 cruise.

<table>
<thead>
<tr>
<th>Station/cast</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Location</th>
<th>Maximum pressure (dbar)</th>
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</tr>
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3.0 CRUISE SUMMARIES

The cruise summaries presented here give an overview of the activities conducted during the 2015 HOT cruises. The official Chief Scientist's reports can be found on the HOT-BEACH (hahana.soest.hawaii.edu/hot/cruises.html) and HOT-PO web pages.

3.1 HOT-269

Chief Scientist: S. CURLESS
R/V Ka‘imikai-O-Kanaloa

Operations during the cruise were compromised due to slow transit speeds and modifications were made to the cruise schedule. To compensate for slow transit speeds to reach Station ALOHA, the planned 200 m CTD cast for an incubation experiment was cancelled and the 1000 m CTD cast for water for the Primary Production Array was conducted to only 200 m. Water needed for the incubation experiment was collected on a CTD cast within the 36 hour CTD burst period instead of collecting samples for PUR. Slow transit speeds back to Station ALOHA from the sediment trap array recovery site cancelled, delayed and re-ordered operations on February 26th. The Hyperpro was conducted before the CTD operations at WHOTS because the 1400 optimum deployment time slot arrived prior to the ship arriving at Station 50. After completing operations at Station ALOHA and WHOTS, there was not enough time to complete planned operations at Station Kaena and still arrive at Snug Harbor on time. Therefore, operations at Station Kaena were cancelled.

A ~2.5 hour delay in science operations was experienced when the CTD squirt boom failed when power to the boom hydraulics was left on for too long during a near bottom CTD cast which resulted in overheated hydraulic fluid. The boom failure occurred during recovery of the near bottom CTD cast, S2C2 on February 24th. The CTD package was suspended above the water outboard of the ship during the ~2.5 hour delay. Repairs were made and CTD operations continued normally until the early morning of February 25th when the retraction motion of the boom became noticeably slower than the extension motion. After inspection by the Chief Engineer it was recommended that CTD operations continue with the slow retraction motion of the boom since repairs to the retraction hydraulics would be too involved to complete at sea.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts, and one 200 m CTD cast were conducted at Station ALOHA. One 200 m yo-yo CTD cast was completed near the WHOTS mooring (Station 50) with five cycles completed.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400- 1430 time slot on February 23rd, 24th, and 26th. The optical package was
deployed two times during the cruise, once around noon and once in the early morning on February 26th.

The ATE was successfully deployed on February 25th. The ship’s fluorometer, anemometers, ADCP and thermostalinograph ran without interruption during the cruise.

Winds during the cruise were from the east at ~15-20kts. Seas were 2-3ft from the east and the swell was from the northwest at ~3-4 ft throughout the cruise. We arrived at Snug Harbor for off-loading on February 27th, at 0830 (HST).

3.2 HOT-270

Chief Scientist: S. CURLESS
R/V Ka'imikai-O-Kanaloa
March 27-31, 2015

Operations at Station Kahe were slightly delayed when during the weight cast it was noticed that one of the sheaves on the Markey winch was not rotating and frozen in place. The weight was recovered and repairs were made to get the sheave rotating freely. Operations continued with the re-deployment of the weight cast. Another slight delay was experienced during the second weight cast to free the wire from being caught under a bolt. The 1000 m CTD at Station Kahe was conducted without incidents.

Operations at Station ALOHA were initially compromised due to slow transit speeds and then significantly compromised by CTD communication problems resulting in ~23 hours of lost science time.

To compensate for the slow transit speed and late arrival on station, the planned 1000 m CTD cast to obtain water for the primary productivity array was shortened to 200 m to assure the array would be deployed before sunrise.

Operations then continued as planned until during the deep CTD cast, bottle #1 would not fire. After several attempts to fire the bottle, it was thought that modem communication with the carousel had been lost. At 4643 dbar on the upcast all communication with the CTD was lost. Power to the CTD was turned off and the instrument package was recovered. Extensive systematic troubleshooting indicated that the CTD was faulty. An inspection of the CTD circuitry revealed several capacitors on the CTD seacable interface board and modem board were shorted and burned out. There is some indication that this was caused by a small amount of water inside the CTD housing, possibly caused by a leaking bulkhead connector. The secondary CTD was put into place within the rosette frame and midway through the testing process communication to the instrumentation was lost. At that time arrangements were made to borrow OTG’s CTD fish and return to Haleiwa small boat harbor to obtain the equipment. The borrowed equipment was installed on our rosette frame and tested during the transit back to Station ALOHA. Upon arrival on station, the rebuilt package was deployed and obtained both water
samples and data successfully. Operations then continued on a modified and compressed cruise plan aimed at collecting as much of the core objectives as possible in what ship time remained.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, seven 1000 m CTD casts, and one 200 m CTD cast were conducted at Station ALOHA. One 200 m yo-yo CTD cast was completed near the WHOTS mooring (Station 50) with four cycles completed.

The Sediment Traps and Primary Production Array were deployed and recovered successfully. Five net tows for the core HOT zooplankton collection were completed successfully; two during the day, and three during the night.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400- 1430 time slot on March 27th, 28th, and 30th. The optical package was deployed one time during the cruise, in the early morning on March 30th.

The ATE was successfully deployed on March 28th. The ship’s fluorometer, anemometers, ADCP and thermostalinograph ran without interruption during the cruise.

Winds during the cruise were from the east at ~15-20kts. Seas were 3-5ft from the east and a ~5ft easterly swell was present throughout the cruise. We arrived at Snug Harbor for off-loading on March 31st, at 0905 (HST)
Operations during the cruise ran as scheduled. The .680 wire, trawl winch and A-frame were used for CTD operations. Two kinks in the wire developed during the first deep cast required reterminating the wire and limiting downcast speeds to 40 mpm. The primary conductivity sensor cable was changed for S2C6.

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. One near bottom cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The ATE operated successfully and one trace metal free sample was collected.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400-1430 time slot on April 20th, 21st and 23rd. The optical package ACS/LISST was deployed two times during the cruise, once around noon and once in the early morning on April 23rd.

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

The winds throughout most of the cruise were from the east at 18-25 kts A east swell of 4-8 ft was present throughout the cruise.
Operations during the cruise ran as scheduled. The .680 wire, trawl winch and A-frame were used for CTD operations. A section of the .680 wire began unraveling at 567 m. OTG taped, marked and monitored the area during the cruise.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, one 200 m CTD cast, and thirteen 1000 m CTD casts were conducted at Station ALOHA. Two yo-yo casts were conducted at Station 50 (WHOTS-11 mooring); 5 cycles (between both casts) were conducted to 200 dbar. These two casts at Station 50 were intended to be only one cast but the package broke the surface after the first cycle and a new cast had to be initiated to continue collecting data. One near bottom cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The ATE operated successfully and one trace metal free sample was collected.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400-1430 time slot on May 22nd, 23rd and 25th. The optical package ACS/LISST was deployed two times during the cruise, once around noon and once in the early morning on May 25th.

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

The winds throughout most of the cruise were from the north and northeast at 10-15 kts. Seas of 4-6 ft were present throughout the cruise.
Operations at Station ALOHA were conducted as planned with the exception of the recovery of the sediment traps which was postponed until after operations at Station ALOHA were complete. The presence of a strong eddy centered to the NW of Station ALOHA provided a strong (~0.8kt) current to the south which caused all of the arrays to drift quickly. The sediment traps drifted 30 miles south of Station ALOHA, making it more efficient to recover them on the way to Station Kaena.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, one 200 m CTD cast 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. One near bottom CTD cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were deployed and recovered successfully. Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The ATE was successfully deployed on June 20th.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400- 1430 time slot on June 18th, 19th, and 21st. The optical package (ACS/Sea Bird Seacat/LISST) was deployed two times during the cruise, once around noon and once in the early morning on June 21st.

The fluorometer, ADCP, thermosalinograph, pCO2 system, and the ship’s meteorological suite ran without interruption during the cruise.

Winds during the cruise were from the northeast at ~15-20kts. Seas were calm and a ~3-5ft northeasterly swell was present throughout the cruise.

We arrived at Snug Harbor for off-loading on June 22nd, at 0805 (HST).
Operations during the cruise ran as scheduled. The .680 wire, trawl winch and A-frame were used for CTD operations.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, two 200 m CTD cast, and twelve 1000 m CTD casts were conducted at Station ALOHA. One yo-yo cast was conducted at Station 52 (WHOTS-12 mooring); 5 cycles were conducted to 200 dbar. One near bottom cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. Three hand net tows were completed by the Caron Lab on July 19th and 20th; two during the day and one at night. The ATE operated successfully and one trace metal free sample was collected.

The Hyperpro casts (three cycles each) were successfully conducted three times around the scheduled 1400-1430 time slot on July 18th, 19th and 21st. The optical package ACS/LISST was deployed two times during the cruise, once around noon and once in the early morning on July 21st.

The fluorometer, ADCP, thermosalinograph, underway pCO2 and the ship’s meteorological suite ran without interruption during the cruise. Sea Gliders sg146 and sg152 were deployed upon arrival to St. ALOHA on July 18th. An ARGO float was deployed at St. ALOHA on July 21st. A SVP drifter was deployed at St. ALOHA on July 21st.

The winds throughout most of the cruise were from northeast at 10-15 kts. Seas of 2-4 ft were present throughout the cruise.
Operations during the cruise were conducted as planned. The cruise was delayed three days because of ship’s engine repairs. There were three issues with the provided equipment that should be addressed before our next cruise on this ship: 1) There was no bottom depth information during the cruise since the Knudsen system was not available, and the Sea-Beam was not operational. 2) The CTD winch tensionmeter was not working correctly, and it seemed to have an offset problem; the system did not register a correct tension during the weight cast, and the displayed tension and wire-out speed were fluctuating erratically during some of the casts. 3) The CTD squirt boom was moving slowly during CTD deployment and recoveries, indicating a possible problem with the hydraulic system.

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 52) with four cycles completed. One near bottom cast was completed at Station Kaena. The first deep cast was about 30 to 40 m off the bottom (4772 dbar) because the altimeter failed and there was no backup system to estimate the distance of the package from the bottom (the Knudsen system was not available to receive the pinger’s signal). The altimeter was replaced with the backup before the second deep cast.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. Six net tows were completed successfully; three during the day, and three during the night.

The optical package ACS/LISST was deployed two times in the morning of August 14th. The ATE was successfully deployed on August 13th.

The underway thermosalinograph system was working fine during the cruise, but it stopped logging data on August 15th at 00:00:30 HST, during the return transit between Kaena Station and Snug Harbor. The underway fluorometer and the ADCP worked correctly during the cruise. The ship’s anemometer ran without interruption during the cruise.

Winds were easterlies between 15 and 25 kts, with moderate seas.
3.8 HOT-276

Chief Scientist: S. CURLESS
R/V Ka‘imikai-O-Kanaloa
September 24-28, 2015

HOT 276 originally departed on September 24\textsuperscript{th}. During operations at Station Kahe it was noticed there was no tension readout on the Markey winch. Further investigations by OTG confirmed that the load cell pin had broken. Without proper equipment on board to fix the problem, we returned to Snug Harbor for repairs.

Once repairs to the load pin were complete (September 25\textsuperscript{th}), the cruise was rescheduled to depart on September 26\textsuperscript{th}. Operations ran as scheduled until the ship began transiting to Station ALOHA. Heavy winds and seas delayed arrival on Station until 0600 September 27\textsuperscript{th}. Weather on station was 10-12 ft swells with 7 ft seas, and 30 kt winds. Science operations were suspended due to heavy weather.

After reviewing weather forecasts, it was decided by the Captain and the Chief Scientist that the gradient between the high pressure system and tropical storm was not going to allow the weather to get better before our scheduled arrival time into the harbor. To save sea days, the cruise returned to Snug Harbor at 0800 on September 28\textsuperscript{th}.

\textbf{Operations completed}: Station Kahe weight cast to 500 m, 1000 m CTD and a Hyperpro deployment. Three SLDMB floats were successfully deployed while departing Station Kahe. One SLDMB float was deployed upon our return to Snug Harbor at the same latitude as the other float deployments. The ship's anemometers, ADCP, thermosalinograph and underway fluorometer ran successfully throughout the cruise.

\textbf{Operations not completed}: All scheduled Station ALOHA, Station WHOTS, and Station Kaena activities. The APEX float was not deployed.
Operations during the cruise were conducted as planned. There were two issues with the provided equipment that should be addressed before our next cruise on this ship: 1) The bottom depth information from the Knudsen system seems to be skewed low compared to past observations, likely as a result of inaccurate sound speed velocity inputs in the system. 2) The CTD squirt boom was moving slowly during CTD deployment and recoveries, indicating a possible problem with the hydraulic system.

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. The secondary conductivity sensor malfunctioned during the first deep cast (S2C2) and the following cast (S2C3). The sensor was replaced before S2C4 and the replacement functioned correctly for all remaining casts. One yo-yo CTD cast was completed near the WHOTS mooring (Station 52) with five cycles completed (four to 200 m, one to 500 m to collect water from that depth). One near bottom cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. The Gas Array was modified due to potential contamination of the $^{15}$N enriched seawater stemming from freezing of the $^{15}$N$_2$ seawater stocks. Only one bottle was attached at each depth.

Six net tows were completed successfully; three during the day, and three during the night. The ATE was successfully deployed on October 14th. On October 15th, at Station ALOHA, the APEX float was deployed without incident and seaglider #512 was successfully recovered.

The Hyperpro casts (three cycles each) were successfully conducted three times during the cruise. The first two were conducted around the scheduled time slot on October 12th and 13th. On October 15th, the final hyperpro cast was conducted earlier than scheduled because the port main engine was not functioning correctly, making transit speeds ~6 kts instead of ~9 kts, requiring an earlier start to the return transit from Station ALOHA to Station Kaena. The engine was fixed during transit, restoring the ship to full speed, and allowing operations at Station Kaena to be conducted on schedule.

Six manta trawl tows were completed successfully, three at Station ALOHA, and three on the transit from Station ALOHA to Station Kaena. Four SLDMB drifters were deployed according to plan, two on October 12th after leaving Station Kahe, and two on October 16th during the return transit at the same latitude.

The underway thermosalinograph system, the underway fluorometer, and the ADCP functioned correctly during the cruise.
The underway seawater samples were collected as planned and the underway seawater plastic filtration system functioned properly. The ship’s anemometer ran without interruption during the cruise.

Winds were from the northeast between about 10 and 15 kts, with moderate seas. A north swell was present throughout the cruise starting at 3-4 ft, then increasing to 7-8 ft, and relaxing to 5 ft on the last day.

3.10 HOT-278

Chief Scientist: R. W. DEPPE
R/V Kilo Moana
November 12-16, 2015

Operations during the cruise were modified significantly from plans due to rough seas and strong winds at Station ALOHA. Winds from the ENE at 25-30 kts and an 8-10 ft swell were present during transit to Station ALOHA. Upon arriving at Station ALOHA, winds were 25 kts and the swell was 8-10 ft. Conditions eased to 20-25 kt winds and 8 ft swells early on the morning of November 13th but increased throughout the day to winds from the ENE at around 25 kts and 8-10 ft seas. The evening of November 14th, easterly winds picked up to mostly between 25 to 30 kts, occasionally exceeding 30 kts, and seas increased to 10-13 ft. These conditions continued for the remainder of time at Station ALOHA and we continued to experience these rough conditions during the transit back from Station ALOHA until we were protected on the leeward side of Oahu.

There was one issue with the provided equipment that should be addressed before our next cruise on this ship. During the deep cast, the Caley winch (with heave compensation running) had a brief run-away with speeds in excess of 60 m/min. An emergency stop was implemented at 4583 dbar on the downcast and the problem was troubleshooted by engineering. After a successful test of the system following a restart of the winch controls, the cast was resumed successfully with the auto-rendering and heave compensation turned off. Heave compensation ran properly in all subsequent casts on the cruise, but none were sent below 1020 dbar. The source of this problem is not understood for certain since the tension was below the rendering set point of 4,900 lbs (and even below the default set point of 3,000 lbs). Possible reasons for this problem and working solutions should be investigated thoroughly before the Caley winch is used with heave compensation during a near-bottom cast.

One 1000 m CTD cast was completed at Station Kahe. One near bottom CTD cast and eleven 1000 m CTD casts were conducted at Station ALOHA. 30-hours of the planned 36-hour burst CTD casts were completed successfully.

Three net tows for the core HOT zooplankton collection were completed successfully; two during the day (1230 on 11/13 and 1000 on 11/14), and one during the night (2200 on 11/13). The ATE was successfully deployed on November 14th.
Three of the Hyperpro casts (three cycles each) were successfully conducted at these times: 1252 on November 12th, and 1000 and 1400 on November 15th. The modified optical package (Sea Bird Seacat/LISST) was deployed one time during the cruise in the early morning on November 15th.

The three planned Repeta pump deployments were conducted successfully at 0118 on November 13th, 0057 on November 14th, and 0200 on November 15th. An additional Repeta pump was conducted at 1224 on November 15th to collect 25-m water that was planned to be collected during the WHOTS cast.

The fluorometer, ADCP, thermosalinograph, and the ship’s meteorological suite ran without interruption during the cruise. The underway seawater plastic filtration system functioned properly.

The pCO2 system was not functioning properly during the cruise. The LICOR detector was unstable and had an irregular ticking sound, possibly the chopper motor, and should be serviced by the manufacturer.

We arrived at Snug Harbor for off-loading on November 16th, at 0735 (HST). After the OTG radioisotope van was unloaded from the ship, the ship was flipped and secured for off-loading by 0817 (HST).

The following operations were cancelled due to the rough seas and winds experienced during the cruise in order to preserve the safety of the personnel and equipment:

1. All six manta trawl tows were cancelled.
2. Deployments of the Sediment Traps, Primary Production Array, and Gas Array were all cancelled due to deployment conditions and forecasted recovery conditions that were too rough for safe and successful operations.
3. The Primary Production CTD cast was cancelled since the purpose of the cast is to collect water for the Primary Production Array.
4. The Hyperpro cast scheduled on 11/13 was cancelled due to the cancellation of the primary production experiment.
5. Three-out-of-six net tows for the core HOT zooplankton collection were cancelled.
6. The last two CTD casts in the 36-hour burst were cancelled: HPLC and PO-3 (the second near-bottom cast at ALOHA). The trend of increased sea state and wind, as well as some undesirable shock loads observed in the tension readout during deployments of the most recent casts (one in excess of 2700 lbs), influenced this decision.
7. The WHOTS yo-yo CTD cast to 200 m was cancelled. Conditions had not improved.
8. The Station Kaena near-bottom CTD cast was cancelled. Conditions had not improved.
Operations during the cruise were conducted as planned with the following exceptions. The CTD wire snapped at the end of the weight cast resulting in the loss of the test weight and electrical termination. The Kahe CTD cast was cancelled and the wire re-terminated in route to St. ALOHA to keep on schedule. Heavy weather caused cancellation of the second deep cast, an optics cast, a Hyperpo cast, the WHOTS cast, and St. Kaena. Rough conditions during recovery of the Sediment Trap array caused the traps to spill and fill with surface water. The samples were unusable and not processed.

The CTD squirt boom was moving slowly during CTD deployment and recoveries due to hydraulic system issues. It failed to retract at the end of the deep cast until additional hydraulic fluid was added to the reservoir delaying recovery for 15 minutes. The ship reported that the boom is due for a full overhaul.

Science Van #24 had electrical breaker issues that made the van unusable. It’s science operations were completed in the ships Clean Lab.

One near bottom CTD casts and thirteen 1000 m CTD casts were conducted at Station ALOHA.

The Primary Production Array, and Gas Array were all deployed and recovered successfully. The Sediment Traps Array samples were comprised during recovery. Six net tows were completed successfully; three during the day, and three during the night. The ATE was successfully deployed on December 9th.

Two Hyperpo casts (three cycles each) were successfully completed. The first on December 7th at St. Kahe and the second on December 8th at St. ALOHA.

Three SLDMB drifters were deployed according to plan on December 7th after leaving Station Kahe. The underway thermosalinograph system, the underway fluorometer, and the ADCP functioned correctly during the cruise. The ship’s anemometer ran without interruption during the cruise.

Winds were light and variable at the beginning of the cruise with a small north swell. Wind and swell built steadily during the cruise with the approach of a cold front. By Wednesday night winds were gusting over 30 knots and remained high for the rest of the cruise causing rough sea conditions.
4.0 RESULTS

4.1 Hydrography

4.1.1 2015 CTD Profiling Data

Profiles of temperature, salinity, oxygen and potential density ($\sigma_\theta$) were obtained from data collected at Stations Kahe, ALOHA, and Kaena. The downcast CTD profiles from Station ALOHA during 2015 are presented in Figures 6.1.1a to j, 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 j). 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, which are 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 j). In some instances mismatches are caused by 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 j. 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 continuous nitrate concentration are shown in Figures 6.1.4a to j. Nitrate profiles show the nutricline to be between 200 and 600 dbar (25.75-27 $\sigma_\theta$).

Profiles of the data collected for Stations Kahe and Kaena during 2015 are presented in Figures 6.1.5.

The potential temperature, salinity and oxygen profiles obtained from the deep casts at Station ALOHA during 2015 are presented in Figures 6.1.6-8.

4.1.2 Time-series Hydrography, 1988-2015

The hydrographic data collected during the first twenty seven years of HOT are presented in a series of contour plots (Figures 6.1.9-24). These figures show the data collected in 2015 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 6.1.9 and 6.1.10 show the contoured time-series for potential temperature and density ($\sigma_\theta$) in the upper 1000 dbar for all HOT cruises through 2015. Seasonal variation in temperature for the upper ocean is apparent in the maximum of near-surface temperature of about 26 °C and the 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 6.1.10). The cruise-to-cruise changes between February and July 1989 in the upper pycnocline illustrate that variability in density is not always well resolved by our quasi-monthly sampling.

Figures 6.1.11-14 show the contoured time-series record for salinity in the upper 1000 dbar for all HOT cruises through 2015. 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 6.1.14 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 the range 24-25 $\sigma_\theta$. 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 normal in early 1995 and 1996, and throughout these two years the values are below 35.2. During 1997 the salinities decrease even further, with values below 35.1, to recover rapidly after February 1998 to values prior to 1995. The increase continues 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. 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 the 1998 through 2004 period of high salinities in the salinity maximum, brief periods of relatively lower salinity are 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 obvious 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 6.1.15 and 6.1.16 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 \( \mu \text{mol kg}^{-1} \) appearing frequently 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 6.1.25). Superimposed on this variability is a general trend towards lower oxygen values from 1989 throughout 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 during 2015.

The surface layer shows a seasonality in oxygen concentrations, with highest values in the winter. This pattern corresponds roughly to the minimum in surface layer temperature (Figure 6.1.9).

Figures 6.1.17-24 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 6.1.17-18). 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 6.1.18). These events are accompanied by a decrease in the oxygen concentration mentioned above (Figure 6.1.16). 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, mid-2008, late-2012, mid-2013, and late 2014 to early 2015. 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 6.1.21-22).

During 1996, the intermediate waters between 27.0-27.8 $\sigma_0$ recovered from anomalously low [nitrate + nitrite] which was observed during 1995 (Figure 6.1.19). This anomaly is apparent in a time series of mean [nitrate + nitrite] between 27.0-27.8 $\sigma_0$ (Figure 6.1.25). 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 $\mu$mol kg$^{-1}$ below 27.5 $\sigma_0$ where nitrate concentrations are about 40 $\mu$mol kg$^{-1}$. This decrease appears to be real 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 $\mu$mol kg$^{-1}$ for samples with a concentration of 40 $\mu$mol kg$^{-1}$. Hence, the 1 $\mu$mol 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 6.1.25). 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 an oxygen decrease in early 2015.

Intermediate water SRP (between 27.0-27.8 $\sigma_0$) reached low values in early 1997, after a decreasing trend established in early 1994 (Figure 6.1.20). A time series of mean SRP in this layer shows this trend clearly (Figure 6.1.25). The SRP maintained relatively low values throughout early 2001, when it increased sharply and maintained an increasing trend until 2005, to then start 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 during 2015. Decreases in phosphate in the deeper waters could persist for long periods of time 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 $\sigma_0$ vary during the decrease of phosphate from early 1994 through 1997 (Figure 6.1.25) 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 2015 HOT cruises are presented in Figures 6.2.1a to k and Figures 6.2.2a to k. 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 station as the ship provides a potential source of contamination and disturbs the water being sampled. As explained earlier (Section 2.2.1), cruises on board the R/V Kilo Moana prior to HOT-271 experienced consistently higher thermosalinograph water temperatures than values obtained with the CTD at
the same depth. This is allegedly due to heating from the pump and was corrected before HOT-271 by repositioning the intake pump.

Thermosalinograph data from HOT-276 aboard the R/V Ka‘imikai-O-Kanaloa was broken into two segments due to a winch-boom tensionometer failure, requiring the vessel to return to shore for repairs. Additional problems with the thermosalinograph system during cruises were indicated in Section 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 k.

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. No WHOTS data was available from mid-July to mid-June.

The thermosalinograph temperatures obtained at Station ALOHA during cruises, are also plotted together 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 k (no WHOTS wind data available for HOT-270 to -273).

Meteorological observations taken at 5 minute intervals on board the R/V Kilo Moana (HOT-271 to -274 and -278) are included in Section 4.10 (Figures 6.10.5.a-e)

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 6, combined (Figures 6.4.2). There was an interruption in logged data during the northbound leg of HOT-269 and during HOT-279. This was later associated with ship underway data technical issues experienced on R/V Ka‘imikai-O-Kanaloa. During HOT-276, only data out to Station Kahe and back were recorded. 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 1988-2015 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 1988-2015 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 CO₂ 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 CO₂ 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 2015. The upper 100 m is generally depleted in [nitrate + nitrite].
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 ~ 1 nmol P l⁻¹) and the precision of the low level P (LLP) determination in oligotrophic seawaters. Figure 6.5.7 presents LLP data from 2015. 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 1989-2015 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 from these historic lows. There appear to be aperiodic injections of DIP (for example in early 1995 & 2012 and less dramatic increases in 1998, 2000, 2001, 2003, 2004, 2007, 2009 & 2014) The mechanism(s) controlling these inventory enhancements are not well understood.

4.5.5 Total Organic Carbon

A contour plot of total organic carbon (TOC) from 0 to 1000 dbar over the 2002-2010 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 (PP) concentrations in the surface ocean over the 27 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 PP 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 PP.

4.5.6.2 Particulate Biogenic Silica

Particulate biogenic silica (PSi) concentrations in the surface ocean over the last 19 years of the program are shown in Figure 6.5.16 and Figure 6.5.17. PSi typically ranges from < 5 to about 25 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 1988-2015 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 1988-2015 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 2015 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 27 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 27 year data set is 528 $\pm$ 137 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)

<table>
<thead>
<tr>
<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>
</tr>
</thead>
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<tr>
<td></td>
<td></td>
<td>Chl a</td>
<td>Pheo</td>
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</tr>
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<td>279</td>
<td>28.22</td>
<td>21.3</td>
<td>28.8</td>
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</table>

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4.6.2 Particle Flux

Particulate carbon (PC), nitrogen (PN), phosphorus (PP) and silica (PSi) fluxes at 150 m are presented in Table 4.2 and Figure 6.6.3 for the 1988-2015 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 PP 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 4.2: Station ALOHA 2015 sediment trap flux data

<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>PP Flux (mg m$^{-2}$ d$^{-1}$)</th>
<th>PSi Flux (mg m$^{-2}$ d$^{-1}$)</th>
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<tr>
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<td>4.2</td>
<td>3.22</td>
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</tbody>
</table>

4.7 Optical Measurements

4.7.1 Solar Irradiance

Incident irradiance (400-700 nm wavelength band) measured using a LICOR LI-1000 during the cruise is shown in Figures 6.7.1a-k (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-273) and lower values in the winter months (HOT-279). 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 18 years we’ve been collecting in-situ PAR data. Both vary seasonally. The average 1 % light-level at Station ALOHA is 106.0 m while the average K$_{PAR}$ between 100 & 150m is 0.0437 m$^{-1}$. Downwelling irradiance measured during the Primary Production incubation period is shown in Table 4.1.
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 100-140m 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 6 x 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 x 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 4 x 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 2 x 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 1994-2015 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-11 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 - 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 NGVMs 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-12 mooring recovery cruise are shown in plots of temperature, conductivity, salinity and dissolved oxygen as a function of depth (Figures 6.10.4.a - g).

Data obtained with the WHOTS buoy meteorological instruments during HOT cruises conducted on the R/V Kilo Moana (HOT-271 to -274 and -278) are shown together with the ship’s meteorological observations taken at 5 minute intervals (Figures 6.10.5.a-e). 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 long wave 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 RM Young and ORG precipitation gauges functioned properly during all cruises, except during HOT-274 which had noisy RM Young data. Short and long wave radiation and PAR data instruments were not working properly during the HOT-273 cruise.

The R/V Kilo Moana’s RM Young RTD air temperature sensor showed low temperatures as compared to the humidity temperature sensor during all cruises.

WHOTS-11 buoy logged data during cruises HOT-271 through -273 in data loggers #7 and #19, however wind data were not available during cruises HOT-271 through -273, and rain data were not available during HOT-273. WHOTS-12 buoy logged data during cruises HOT-274 and -278 in data loggers #8 and #9.
5.0 REFERENCES


6.0 FIGURES

6.1 Hydrography

Figure 6.1.1a-j: [Upper left panel] Temperature, salinity, oxygen and potential density ($\sigma_\theta$) 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-j: [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. Offset is 0.1.

Figure 6.1.3a-j: Stack plots of CTD chloropigment (fluorescence) and bottle fluorometric chlorophylls+pheopigments versus pressure to 200 dbar [1st panel] and versus to 25.5 kg/m³ [2nd panel] at Station ALOHA. Chloropigment values have been offset by 0.2 μg/l for both plots.

Figure 6.1.4a-j: Stack plots of CTD nitrate and bottle inorganic [nitrate+nitrite] versus pressure to 1000 dbar [1st panel] and versus to 27.5 kg/m³ [2nd panel] at Station ALOHA. Nitrate values have been offset by 5 μmol/kg for both plots.

Figure 6.1.5a-j: [Upper left panel] Temperature, salinity, oxygen and potential density ($\sigma_\theta$) 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 $\sigma_\theta$ 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 6.1.6: [Upper panel] Potential temperature versus pressure for all deep casts in 2015. [Lower panel]: Potential temperature versus pressure deeper than 2500 dbar for all deep casts in 2015.

Figure 6.1.7: [Upper panel] Salinity versus potential temperature for all deep casts in 2015. [Lower panel]: Salinity versus potential temperature for all deep casts in 2015 in the 1-5 °C range.

Figure 6.1.8: [Upper panel] Oxygen concentrations from calibrated oxygen sensor data versus potential temperature for all deep casts in 2015. [Lower panel] Oxygen versus potential temperature for all deep casts in 2015 in the 1-5 °C range.

Figure 6.1.9: Contour plot of CTD potential temperature versus pressure for HOT cruises 1-279.
**Figure 6.1.10**: Contour plot of $\sigma_0$, calculated from CTD pressure, temperature and salinity, versus pressure for HOT cruises 1-279.

**Figure 6.1.11**: Contour plot of CTD salinity versus pressure for HOT cruises 1-279.

**Figure 6.1.12**: Contour plot of CTD salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.13**: Contour plot of bottle salinity versus pressure for HOT cruises 1-279. The solid circles indicate location of samples in the water column.

**Figure 6.1.14**: Contour plot of bottle salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.15**: Contour plot of bottle oxygen versus pressure for HOT cruises 1-279. The solid circles indicate location of samples in the water column.

**Figure 6.1.16**: Contour plot of bottle oxygen versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.17**: Contour plot of [nitrate + nitrite] versus pressure for HOT cruises 1-279. The solid circles indicate location of samples in the water column.

**Figure 6.1.18**: Contour plot of [nitrate + nitrite] versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.19**: Contour plot of [nitrate + nitrite] versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-279.

**Figure 6.1.20**: Contour plot of soluble reactive phosphorus versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-279.

**Figure 6.1.21**: Contour plot of soluble reactive phosphorus versus pressure for HOT cruises 1-279. The solid circles indicate location of samples in the water column.

**Figure 6.1.22**: Contour plot of soluble reactive phosphorus versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.23**: Contour plot of silicate versus pressure for HOT cruises 1-279. The solid circles indicate location of samples in the water column.

**Figure 6.1.24**: Contour plot of silicate versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-279. A heavy line connects the average $\sigma_0$ at the sea surface.
Figure 6.1.25: Time series of mean bottle dissolved oxygen for HOT cruises 1-279 (upper panel), [nitrate + nitrite] (middle panel) and soluble reactive phosphorus (lower panel) between 27.0 and 27.8 $\sigma_\theta$ isopycnals. The smooth line is the spline fit to the data. The asterisks indicate the annual mean.

6.2 Thermosalinograph

Figure 6.2.1a-k: Thermosalinograph data for HOT-269 through -279 cruises in 2015. Continuous near-surface temperature, salinity and $\sigma_\theta$ (continuous lines), CTD data at the 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-k: Navigation data during HOT-269 through -279 cruises in 2015: 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 2015 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 2015 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 2015 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 2015 HOT cruises.

Figure 6.3.3: [Upper panel] Sea surface temperature minus dry air temperature while at Station ALOHA for 2015 HOT cruises (open circles), and WHOTS buoy hourly measurements throughout the year (continuous line). [Lower panel] Relative humidity at Station ALOHA for 2015 HOT cruises, and WHOTS buoy hourly measurements throughout the year (continuous line).

Figures 6.3.4a to k: [Upper panel] True winds measured at Station ALOHA for 2015 HOT cruises. [Middle panel] Continuous true wind record from the ship’s anemometer during HOT cruises. [Lower panel] True winds measured by WHOTS buoy (no WHOTS wind data available for HOT-270 to -273). The orientation of the arrows indicates the wind direction; up is northward, right is eastward.
6.4 ADCP Measurements

Figures 6.4.1a-k: Velocity fields at Station ALOHA were obtained with an RD Instruments Ocean Surveyor 38 kHz in narrow band mode during 2015 cruises, except during HOT-269, 270, 275, 276, 277, and 279 which were conducted on the R/V Kaʻimikai-O-Kanaloa using an RD Instruments Work Horse 300 kHz. 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 show 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. The gaps in some of the station data are due to excursions to retrieve the primary productivity array and floating sediment traps.

Figures 6.4.2a-k: Velocity fields on the transits to and from Station ALOHA and Station 6 obtained with an RD Instruments Ocean Surveyor 38 in narrow band mode, except during HOT-263 which was conducted on the R/V Kaʻimikai-O-Kanaloa using an RD Instruments Work Horse 300 kHz. 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 1-279 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 1-279. [Lower panel] Mixed layer dissolved inorganic carbon (normalized to 35 ppt salinity) for HOT cruises 1-279. 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 1-279 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 1-279 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 2015 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 1-279. [Lower panel] 0-100 dbar integral of LLN at Station ALOHA for HOT cruises 1-279.

**Figure 6.5.7**: Depth profile from 0-250 dbar of low-level soluble reactive phosphorus at Station ALOHA for 2015 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 1-279. [Lower panel] 0-100 dbar integral of LLP at Station ALOHA for HOT cruises 1-279.

**Figure 6.5.9**: Contour plot from 0-1000 dbar of total organic carbon at Station ALOHA for HOT cruises 134-227. Solid dots indicate water column sample locations.

**Figure 6.5.10**: [Upper panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-279 from 0-50 dbar. [Lower panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-279 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 1-279. Solid dots indicate water column sample locations.

**Figure 6.5.12**: [Upper panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-279 from 0-50 dbar. [Lower panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-279 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 1-279. Solid dots indicate water column sample locations.

**Figure 6.5.14**: [Upper panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-279 from 0-50 dbar. [Lower panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-279 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 1-279. Solid dots indicate water column sample locations.

**Figure 6.5.16**: [Upper panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-279 from 0-50 dbar. [Lower panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-279 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 79-279. 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 2-279. 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 1-279.

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 1-279.

Figure 6.5.21: Contour plots from 0-200 dbar of HPLC photo-protective carotenoid (diadinoxanthin, zeaxanthin & \( \alpha \)- plus \( \beta \)-carotene) concentrations at Station ALOHA for HOT cruises 1-279.

Figure 6.5.22: Contour plot from 0-350 dbar of particulate adenosine 5'-triphosphate concentrations at Station ALOHA for HOT cruises 1-279. 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 1988-2015. Filled circles and crosses indicate \textit{in situ} and on deck incubations, respectively. Solid line represents the average production (528 mg C m\(^{-2}\) d\(^{-1}\)), dashed lines are \pm one standard deviation (137 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 1-279. Solid dots indicate water column sample locations.

Figure 6.6.3: Particulate carbon flux [Top panel], Particulate nitrogen flux [2\(^{nd}\) panel], Particulate phosphorus flux [3\(^{rd}\) panel] and Particulate silica flux [Bottom panel] at 150 m measured on all HOT cruises from 1988-2015. Error bars represent the standard deviation of determinations from triplicate particle interceptor traps.

6.7 Optical Measurements

Figure 6.7.1a–k: [Upper panel] Incident irradiance (400-700 nm wavelength band) measured using a Li-COR LI-1000 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\( \alpha \) : 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 90-279. The solid red line represents the average 1% surface PAR light depth (106.0 m) at Station ALOHA. [Lower panel] Mean PAR attenuation coefficient ($K_{\text{PAR}}$) for HOT cruises 90-279 from 100-150m. The solid red line represents the average $K_{\text{PAR}}$ (0.0437 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 2015.

**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 177-279. 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 2015.

**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 23-279. 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 51-279. Both nighttime (blue) and daytime (red) biomass are plotted.

### 6.10 WHOTS Mooring

**Figure 6.10.1.a**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 1.5 m on the WHOTS-11 mooring.

**Figure 6.10.1.b**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 7 m on the WHOTS-11 mooring.

**Figure 6.10.1.c**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 15 m on the WHOTS-11 mooring.
**Figure 6.10.1.d**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 25 m on the WHOTS-11 mooring.

**Figure 6.10.1.e**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 35 m on the WHOTS-11 mooring.

**Figure 6.10.1.f**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 40 m on the WHOTS-11 mooring.

**Figure 6.10.1.g**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 45 m on the WHOTS-11 mooring.

**Figure 6.10.1.h**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 50 m on the WHOTS-11 mooring.

**Figure 6.10.1.i**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 55 m on the WHOTS-11 mooring.

**Figure 6.10.1.j**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 65 m on the WHOTS-11 mooring.

**Figure 6.10.1.k**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 75 m on the WHOTS-11 mooring.

**Figure 6.10.1.l**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 85 m on the WHOTS-11 mooring.

**Figure 6.10.1.m**: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 95 m on the WHOTS-11 mooring.

**Figure 6.10.1.n**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 105 m on the WHOTS-11 mooring.

**Figure 6.10.1.o**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 120 m on the WHOTS-11 mooring.

**Figure 6.10.1.p**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 135 m on the WHOTS-11 mooring.

**Figure 6.10.1.q**: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 deployed at 155 m on the WHOTS-11 mooring.

**Figure 6.10.1.r**: Temperature, salinity and potential density ($\sigma_0$) from Seacat SBE-16 deployed at 4671 m on the WHOTS-11 mooring.

**Figure 6.10.1.s**: Temperature, salinity and potential density ($\sigma_0$) from Seacat SBE-16 deployed at 4671 m on the WHOTS-11 mooring.
**Figure 6.10.1.t**: Temperature, salinity and potential density ($\sigma_0$) contours as a function of depth and time from Microcat instruments in the WHOTS-11 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-11 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-11 mooring.

**Figure 6.10.3**: Zonal and meridional current velocity as a function of time for the NGVMs deployed at 10 and 30 m on the WHOTS-11 mooring.

**Figure 6.10.4.a**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 50 cast 1 and Station 50 cast 2.

**Figure 6.10.4.b**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 50 casts 3 and 4.

**Figure 6.10.4.c**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 50 casts 5 and 6.

**Figure 6.10.4.d**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 52 casts 1 and 2.

**Figure 6.10.4.e**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 52 casts 3 and 4.

**Figure 6.10.4.f**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 52 cast 5 and 6.

**Figure 6.10.4.g**: Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-12 cruise, CTD Station 52 cast 7.

**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-271 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 station ALOHA was occupied.

**Figure 6.10.5.a.2**: Time-series of short wave radiation [top panel]; long wave 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-271 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 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-271 cruise. The plots also include data from the WHOTS buoy instruments (circles). The vertical solid lines indicate the initial and final time when station ALOHA was occupied.

Figure 6.10.5.b.1: Same as in Figure 6.10.5.a.1, but for the HOT-272 cruise.

Figure 6.10.5.b.2: Same as in Figure 6.10.5.a.2, but for the HOT-272 cruise.

Figure 6.10.5.b.3: Same as in Figure 6.10.5.a.3, but for the HOT-272 cruise.

Figure 6.10.5.c.1: Same as in Figure 6.10.5.a.1, but for the HOT-273 cruise.

Figure 6.10.5.c.2: Same as in Figure 6.10.5.a.2, but for the HOT-273 cruise.

Figure 6.10.5.c.3: Same as in Figure 6.10.5.a.3, but for the HOT-273 cruise.

Figure 6.10.5.d.1: Same as in Figure 6.10.5.a.1, but for the HOT-274 cruise.

Figure 6.10.5.d.2: Same as in Figure 6.10.5.a.2, but for the HOT-274 cruise.

Figure 6.10.5.d.3: Same as in Figure 6.10.5.a.3, but for the HOT-274 cruise.

Figure 6.10.5.e.1: Same as in Figure 6.10.5.a.1, but for the HOT-278 cruise.

Figure 6.10.5.e.2: Same as in Figure 6.10.5.a.2, but for the HOT-278 cruise.

Figure 6.10.5.e.3: Same as in Figure 6.10.5.a.3, but for the HOT-278 cruise.
7.0 HOT PROGRAM PRESENTATIONS AND PUBLICATIONS

The following is a listing of Presentations & Publications as of April 2017. 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 Census 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.


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 (N2) 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 CO$_2$ 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.


244. 2014 Sadler, D. W., J. E. Dore, M. J. Church, L. A. Fujieki and D. M. Karl. Assessing the internal consistency of CO₂ measurements at Station ALOHA. Ocean Sciences Meeting (049), Honolulu, HI, February 2014.


251. 2015 Martinez-Garcia, S.; Karl, D. M. Microbial respiration in the euphotic zone at Station ALOHA. ASLO Aquatic Sciences Meeting (063), Granada, Spain, February 2015.


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, N2-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.


290. 2017 Viviani, D. A.; Böttjer, D.; Letelier, R. M.; Church, M. J. The Influence of abrupt increases in seawater pCO$_2$ on rates of microbial production in the subtropical North Pacific Ocean. 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


40. 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.


72. 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.


75. 1996 Firing, E. Currents observed north of Oahu during the first five years of HOT. Deep-Sea Research II 43, 281-303.
159


134. 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.


188. 2001 Lee, K. Global net community production estimated from the annual cycle of surface water total dissolved inorganic carbon. Limnology and Oceanography 46(6), 1287-1297.


composition from remote sensing data. Global Biogeochemical Cycles 16(4),

221. 2002 Karl, D. M. Nutrient dynamics in the deep blue sea. Trends in Microbiology 10(9):
410-418.

415(6872), 590-591.

Earth (Proceedings of the Global Change Open Science Conference 2001), ed W. Steffen

organic matter production and phototrophic microbial community structure in the North
Phytoplankton Productivity and Carbon Assimilation in Marine and Freshwater


Biogeochemistry, 57/58: 47-98.

227. 2002 Landry, M. R. Integrating classical and microbial food web concepts: Evolving views

228. 2002 Landry, M. R. and D. L. Kirchman. Microbial community structure and variability in

production in the nitrate-depleted tropical and subtropical oceans. Geophysical Research

Bidigare, D. K Steinberg and C. A. Carlson. Refining our understanding of oceanic
biogeochemistry and ecosystem functioning. EOS, Transactions, American Geophysical
Union 83: 559, 566-567.

231. 2002 Lutz, M., R. Dunbar and K. Caldeira. Regional variability in the vertical flux of
particulate organic carbon in the ocean interior. Global Biogeochemical Cycles 16(3),
doi:10.1029/2000GB001383

complexity marine ecosystem model for the global domain. Deep-Sea Research II 49, 403-
462.

Steinberg and D. M. Karl. Differences in the biological carbon pump at three subtropical
ocean sites. Geophysical Research Letters, 29(18): 32-1 to 32-4, doi:


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395. 2008 Duennebier, F., D. Harris, and J. Jolly. ALOHA Cabled Observatory will Monitor Ocean in Real Time. Sea Technology, 49(2), 51-54.


486. 2010 Chavanne, C., P. Flament, G. Carter, M. Merrifield, and D. Luther. The Surface Expression of Semidiurnal Internal Tides near a Strong Source at Hawaii. Part I:


North Pacific estimated from accumulated carbonate data. Papers in Meteorology and Geophysics 62, 47-56.


crenarchaeal autotrophic ammonia oxidizers to the dark primary production in Tyrrhenian deep waters (Central Mediterranean Sea). ISME Journal 5(6), 945-961.


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.
632. 2014 Howe, B. M. A Deep Cabled Observatory: Biology and Physics in the Abyss. EOS, Transactions American Geophysical Union, 95 (47), 429-444.


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### 7.3 Submitted Papers


7.4 Thesis and Dissertations


7.5 Data Reports and Manuals


### 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


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


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**


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, are available from a pair of Workstations at the University of Hawaii, and may be accessed using anonymous File Transfer 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 data are in a subdirectory called /pub/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. The workstation's Internet address is ftp://mananui.soest.hawaii.edu. All hydrographic information reside at this address. Biogeochemical and optical data are stored at ftp://ftp.soest.hawaii.edu/dkarl/hot.

1. FTP into mananui.soest.hawaii.edu.

2. Enter anonymous as the user name.

3. Enter your e-mail address as the password.

4. The HOT database is in /pub/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.

6. Biogeochemical and optical parameters are located on a different server. FTP into ftp.soest.hawaii.edu follow steps 2 and 3, then change directories to /dkarl/hot.

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 http://www.soest.hawaii.edu/HOT_WOCE/regis-form.html. 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 [http://hahana.soest.hawaii.edu/hot/hot.html](http://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 [http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html](http://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)
  - **Macroploplankton** (Nets)
  - **Epi Microscopy**
  - **Particle Flux**
  - **Primary Production**

- **Display**
  - **Bottle** (discrete)
  - **CTD** (continuous)
  - **HPLC Pigments**
  - **Epi Microscopy**
  - **Particle Flux**
  - **Primary Production**
  - **Solar Irradiance**
  - **PRR (Ir)radiance**
  - **Hyperspectral (Ir)radiance**
  - **TSRB (Ir)radiance**
  - **Fast Repetition 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 Microscopy
  - Primary Production
  - User Defined

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

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

• **Miscellaneous**
  - Mixed-layer Depth
  - Cruise Summary
Figure 6.1.1a
Figure 6.1.1b
Figure 6.1.1c
Figure 6.1.1d
Figure 6.1.1e
Figure 6.1.1g
Figure 6.1.1h
Station ALOHA  HOT 278

Figure 6.1.1i
Figure 6.1.1j
Figure 6.1.2a
Figure 6.1.2b
Figure 6.1.2c
Figure 6.1.2d
Figure 6.1.2e
Figure 6.1.2g
Figure 6.1.2h
Figure 6.1.2i
Figure 6.1.3a
Figure 6.1.3b
Figure 6.1.3d
Figure 6.1.3e
Figure 6.1.3f
Figure 6.1.3g
Figure 6.1.3i
Figure 6.1.3j
Figure 6.1.4a
Figure 6.1.4b
Figure 6.1.4c
Figure 6.1.4d
Figure 6.1.4e
Figure 6.1.4f
Figure 6.1.4h
Figure 6.1.4i
Figure 6.1.4j
Figure 6.1.5a
Figure 6.1.5b
Figure 6.1.5c
Figure 6.1.5d
Figure 6.1.5f
Figure 6.1.5g
Figure 6.1.5h
Figure 6.1.5i
Figure 6.1.5j
HOT 269-279 WOCE deep casts

HOT 269-279 WOCE deep casts

Figure 6.1.7
Figure 6.1.12
Figure 6.1.13

HOT 1–279 Bottle Salinity

Pressure (dbar)
HOT 1–279 Bottle Salinity

Figure 6.1.14
Figure 6.1.16
Figure 6.1.20
Figure 6.1.21
**Figure 6.1.25**

**HOT 1–279 Mean Oxygen between σθ 27.0 and 27.8**

**HOT 1–279 Mean [Nitrate+Nitrite] between σθ 27.0 and 27.8**

**HOT 1–279 Mean Soluble Reactive Phosphorus between σθ 27.0 and 27.8**
Figure 6.2.1a
HOT-271 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle
HOT-272 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Figure 6.2.1d
HOT-273 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

June 2015 (UTC)

Figure 6.2.1e
HOT-274 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

July 2015 (UTC)

Figure 6.2.1f
HOT-275 Themosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

August 2015 (UTC)

Figure 6.2.1g
HOT-277 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

![Diagram](image-url)
HOT-278 Thermosalinograph, o=CTD at 6 dbar, x=salinity bottle

Figure 6.2.1j
HOT-279 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle.

Temperature (°C)

Salinity

$\sigma_\theta$

December 2015 (UTC)
HOT-269 Navigation and Ship Speed

February 2015 (UTC)
HOT-270 Navigation and Ship Speed

March–April 2015 (UTC)

Figure 6.2.2b
HOT-271 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

April 2015 (UTC)

Figure 6.2.2c
HOT-272 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

May 2015 (UTC)

Figure 6.2.2d
HOT-273 Navigation and Ship Speed

June 2015 (UTC)
HOT-274 Navigation and Ship Speed

July 2015 (UTC)
HOT-275 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

August 2015 (UTC)

Figure 6.2.2g
HOT-276 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

September 2015 (UTC)

Figure 6.2.2h
Figure 6.2.2j
HOT-279 Navigation and Ship Speed

December 2015 (UTC)
HOT 269–279 Atmospheric Pressure

Sea Surface Temperature

Figure 6.3.1
HOT 269–279 SST – Dry Air Temperature

SST – dry air temperature (°C)

Relative Humidity

Relative Humidity (%)

Figure 6.3.3
HOT 269 – Shipboard Winds, Observed

HOT 269 – Shipboard Winds, from the continuous record of the ship

HOT 269 – True Winds, WHOTS buoy data

Figure 6.3.4a
HOT 270 – Shipboard Winds, from the continuous record of the ship

Figure 6.3.4b
HOT 271 – Shipboard Winds, Observed

HOT 271 – Shipboard Winds, from the continuous record of the ship

Figure 6.3.4c
HOT 272 – Shipboard Winds, Observed

HOT 272 – Shipboard Winds, from the continuous record of the ship

Figure 6.3.4d
HOT 274 – Shipboard Winds, Observed

HOT 274 – Shipboard Winds, from the continuous record of the ship

HOT 274 – True Winds, WHOTS buoy data

Figure 6.3.4f
HOT 275 – Shipboard Winds, Observed

HOT 275 – Shipboard Winds, from the continuous record of the ship

HOT 275 – True Winds, WHOTS buoy data

Figure 6.3.4g
Figure 6.3.4h
HOT 277 – Shipboard Winds, Observed

HOT 277 – Shipboard Winds, from the continuous record of the ship

HOT 277 – True Winds, WHOTS buoy data

Figure 6.3.4i
HOT 278 – Shipboard Winds, Observed

HOT 278 – Shipboard Winds, from the continuous record of the ship

HOT 278 – True Winds, WHOTS buoy data

Figure 6.3.4j
HOT 279 – Shipboard Winds, Observed

HOT 279 – Shipboard Winds, from the continuous record of the ship

HOT 279 – True Winds, WHOTS buoy data

Figure 6.3.4k
2015 Days

mean + trend

semi-djurnal 12.42 hours
diurnal 24 hours

0.1 m/s

Velocity On Station

HOT-269

Harmonic Analysis of Velocity

Figure 6.4.1a
Figure 6.4.1b
Velocity On Station

Depth (m)

-1600 -1400 -1200 -1000 -800 -600 -400 -200 0 0.1 m/s

2015 Days

Harmonic Analysis of Velocity

Depth (m)

mean + trend

semidiurnal 12.42 hours
diurnal 24 hours

Figure 6.4.1c
Figure 6.4.1d
Velocity On Station

Harmonic Analysis of Velocity

mean + trend
semidiurnal 12.42 hours
diurnal 24 hours

Figure 6.4.1f
Velocity On Station

Harmonic Analysis of Velocity

HOT-275

0.1 m/s

Depth (m)

2015 Days

mean
+ trend
12.42 hours
semidiurnal
24 hours

diurnal

Figure 6.4.1g
Figure 6.4.1h
Figure 6.4.1j
Figure 6.4.1k
Figure 6.4.2a
Figure 6.4.2b
Figure 6.4.2c
Figure 6.4.2d
Figure 6.4.2e
Figure 6.4.2g
Figure 6.4.2h
Figure 6.4.2i
Figure 6.4.2j
HOT 1−279

Total Alkalinity [μeq kg⁻¹] (35 ppt)

Sampling Date

HOT 1−279

Dissolved Inorganic Carbon [μmol kg⁻¹] (35 ppt)

Sampling Date

Figure 6.5.2
HOT 1-279 Dissolved Inorganic Carbon [μmol kg$^{-1}$]

HOT 1-279 Dissolved Inorganic Carbon [μmol kg$^{-1}$] (35 ppt)

Figure 6.5.3
Figure 6.5.5
HOT 1-279 Low-Level NO$_2$+NO$_3$ [nmol kg$^{-1}$]

Figure 6.5.6
Figure 6.5.7
Figure 6.5.7 continued
HOT 134-227 Total Organic Carbon [μmol kg⁻¹]

Figure 6.5.9
Figure 6.5.10
HOT 1-279 Particulate Carbon [μmol kg⁻¹]
Figure 6.5.12

HOT 1–279 (0–50 dbar means)

HOT 1–279 (50–100 dbar means)
HOT 1–279 (0–50 dbar means)

Particulate Phosphorus [nmol kg\(^{-1}\)]

Sampling Date

HOT 1–279 (50–100 dbar means)

Particulate Phosphorus [nmol kg\(^{-1}\)]

Sampling Date

Figure 6.5.14
HOT 1-279 Particulate Phosphorus [nmol kg$^{-1}$]

Figure 6.5.15
HOT 79−279 (0−50 dbar means)

Sampling Date

HOT 79−279 (50−100 dbar means)

Sampling Date

Particulate Silica [nmol kg\(^{-1}\)]

Figure 6.5.16
Figure 6.5.19
HOT 1-279 19'-Butanoyloxyfucoxanthin [$\mu g$ m$^{-3}$]

HOT 1-279 Fucoxanthin [$\mu g$ m$^{-3}$]

HOT 1-279 19'-Hexanoyloxyfucoxanthin [$\mu g$ m$^{-3}$]

Figure 6.5.20
HOT 1-279 Diadinoxanthin [$\mu$g m$^{-3}$]

HOT 1-279 Zeaxanthin [$\mu$g m$^{-3}$]

HOT 1-279 Carotenoids [$\mu$g m$^{-3}$]

Figure 6.5.21
Figure 6.5.22
Figure 6.6.1
Figure 6.6.3
HOT–269, int = 42.54 [E m\(^{-2}\) d\(^{-1}\)]

Figure 6.7.1a
HOT–270, int = 50.36 [E m\(^{-2}\) d\(^{-1}\)]

Figure 6.7.1b
HOT–271, int = 50.65 \text{ [E m}^{-2} \text{ d}^{-1}] \]

![Graphs showing seasonal variations in PAR and KPAR.](image)

Figure 6.7.1c
HOT–272, int = 50.16 [E m\(^{-2}\) d\(^{-1}\)]
HOT–273, int = 58.10 [E m\(^{-2}\) d\(^{-1}\)]
HOT–274, int = 49.60 [E m$^{-2}$ d$^{-1}$]

Figure 6.7.1f
HOT–275, int = 54.02 [E m$^{-2}$ d$^{-1}$]

Figure 6.7.1g
Figure 6.7.1h
HOT–277, int = 43.11 [E m$^{-2}$ d$^{-1}$]

**Incident Irradiance (μE m$^{-2}$ s$^{-1}$)**

- HOT–277, int = 43.11 [E m$^{-2}$ d$^{-1}$]

**Depth (m)**

**PAR$\alpha$ (μE cm$^{-2}$ s$^{-1}$)**

**$K_{PAR}$ (m$^{-1}$)**

Figure 6.7.1i
Figure 6.7.1j
HOT–279, int = 28.22 [E m^{-2} d^{-1}]

Figure 6.7.1k
HOT 90–279 1% Light Level

HOT 90–279 (100–150 m means)

Figure 6.7.2
Figure 6.7.3
Figure 6.8.1 continued
Figure 6.8.3
Figure 6.8.3 continued
HOT 23-279 Synechococcus [\# \cdot 10^5/ml]

HOT 23-279 Eukaryotes [\# \cdot 10^5/ml]

Figure 6.8.4
Figure 6.9.1
WHOTS-11, 7 m. SN 6892

Pressure (dbar)

Temperature (°C)

Salinity

ρ_θ (kg m^-3)

Sep14 Oct14 Dec14 Feb15 Mar15 May15 Jul15

Figure 6.10.1.b
WHOTS−11, 25 m. SN 4663

Temperature (°C)

Salinity

σθ (kg m⁻³)

Fig. 6.10.1.d

Time Period: Sep14 to Jul15

Temperature

Salinity

σθ (kg m⁻³)

Time Period: Sep14 to Jul15
WHOTS−11, 45 m. SN 3668

Pressure (dbar)

Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.g
Temperature (°C)

Salinity

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

Figure 6.10.1.h
WHOTS–11, 75 m. SN 3632

Temperature (°C)

Salinity

σθ (kg m$^{-3}$)

Figure 6.10.1.k
Temperature (°C)

Salinity

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

Figure 6.10.1.m
WHOTS−11, 105 m. SN 2769

Pressure (dbar)

Temperature (°C)

Salinity

σθ (kg m$^{-3}$)

Figure 6.10.1.n
Pressure (dbar)

Temperature (°C)

Salinity

Figures 6.10.1.jpg
WHOTS−11, 155 m. SN 4701

Pressure (dbar)

Temperature (°C)

Salinity

σθ (kg m⁻³)

Sep14 Oct14 Dec14 Feb15 Mar15 May15 Jul15

Figure 6.10.1.q
WHOTS-11, 4671 m. SN 1880

Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.r
Figure 6.10.1.t
Figure 6.10.2.a
WHOTS-12 Cruise CTD  Yo-Yo : Station 50 Cast 1

WHOTS-12 Cruise CTD  Yo-Yo : Station 50 Cast 2

Figure 6.10.4.a
Figure 6.10.4.b
Figure 6.10.4.c
WHOTS-12 Cruise CTD  Yo-Yo : Station 52 Cast 5

Temperature (°C)

Pressure (dbar)

Conductivity (S/m)

Salinity

Oxygen (µmol kg⁻¹)

WHOTS-12 Cruise CTD  Yo-Yo : Station 52 Cast 6

Temperature (°C)

Pressure (dbar)

Conductivity (S/m)

Salinity

Oxygen (µmol kg⁻¹)

Figure 6.10.4.f
HOT-271 Red – Port anemometer; Blue – Starboard anemometer

Relative Wind Speed (m/s)

Relative Wind Direction (°)

Ship Speed (m/s)

Ship Heading (°)

Red – Port anemometer, Blue – Starboard anemometer, o = WHOTS-11 Logger #7, x = WHOTS-11 Logger #19

True Wind Speed (m/s)

True Wind Direction (°)

Day (2015)
Figure 6.10.5.a.2
HOT−271 Red line = Kilo Moana, o = WHOTS−11 Logger #7, x = WHOTS−11 Logger #19

Pressure

ORG Rain Rate

ORG Rain accum

RM Young Precip

Day (2015)

Figure 6.10.5.a.3
HOT–272 Red line = Kilo Moana, o = WHOTS–11 Logger #7, x = WHOTS–11 Logger #19

Figure 6.10.5.b.3
HOT−273 Red line = Kilo Moana, o = WHOTS−11 Logger #7, x = WHOTS−11 Logger #19

Figure 6.10.5.c.3
Figure 6.10.5.d.2
HOT-274 Red line = Kilo Moana, o = WHOTS-12 Logger #8, x = WHOTS-12 Logger #9

Figure 6.10.5.d.3