PREFACE

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.

This document reports the data collected in 2012. However, we have included some data from 1988-2011 to place the 2012 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, meteorological, navigational, thermosalinograph and ADCP observations. 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 (FTP), the World Wide Web (WWW) or the Hawaii Ocean Time-series Data Organization and Graphical System (HOT-DOGS).
ACKNOWLEDGMENTS

Many people participated in the 2012 cruises sponsored by the HOT program. Special thanks are due to Susan Curless, Joseph Gum, Adriana Harlan, Sean Jungbluth, Dan Sadler, Jefrey Snyder, Brett Updyke, Donn Viviani and Blake Watkins for the tremendous amount of time and effort they have put into the program. Special thanks are given to Georgia Tanaka and Kellie Terada for their excellent administrative support of the program and Julia Hummon for providing training and advice during the ADCP data processing. Adriana Harlan and Eric Grabowski performed many of the core chemical analyses. Karin Björkman, Susan Curless and Brett Updyke performed the nutrient analyses. Dan Sadler performed the carbon analyses. Cameron Fumar, Craig Nosse and Daniel McCoy performed the salinity measurements. Joseph Gum and Branden Obra performed CTD processing. Nicholas Seymour and Branden Nakahara 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 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 grants which supported our 2012 work are NSF grants OCE-09-26766 (Church, Bidigare, Karl and Lukas) and OCE-07-52606 (Lukas).
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 zooplankton and plankton community structure measurements; and C) Ricardo Letelier oversees 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 Plueddmann (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 2012

<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>Zooplankton and plankton community structure</td>
</tr>
<tr>
<td>Ricardo Letelier (collaborator)</td>
<td>Inherent optical properties and satellite remote sensing</td>
</tr>
<tr>
<td>Roger B. Lukas (co-PI)</td>
<td>Physical oceanography component</td>
</tr>
<tr>
<td>Robert Weller &amp; Al Plueddmann (collaborators)</td>
<td>WHOTS (full ocean depth) mooring</td>
</tr>
</tbody>
</table>

1.3 Scientific objectives for HOT

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

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

In addition to these primary objectives, the HOT Program provides logistical support for numerous complementary research programs (Table 1.2). A complete listing of these projects can be obtained from the HOT-BEACH web page (hahana.soest.hawaii.edu/hot/ancillary.html).
Table 1.2: Ancillary Projects Supported by HOT in 2012

<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 CO$_2$ 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>Henrieta Dulaiova &amp; Ken Buesseler</td>
<td>UH</td>
<td>NSF</td>
<td>Japanese radionuclide release sampling</td>
</tr>
<tr>
<td>Karl, Chisholm, Zehr &amp; DeLong</td>
<td>Various</td>
<td>NSF</td>
<td>C-MORE</td>
</tr>
<tr>
<td>Adina Paytan</td>
<td>UCSC</td>
<td>NSF</td>
<td>$^{18}$O natural abundance</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>
<tr>
<td>Angel White</td>
<td>OSU</td>
<td>NASA</td>
<td>Particle size and productivity</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_jgos).
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 2012. Starting point of deployment indicated by “S”. [Right panels] CTD cast locations during each HOT cruise in 2012. Location numbers correspond to cast numbers. Dashed line indicates the 10 km radius circle defining the station.
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
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 2012.

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
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 km² 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 into the mixed layer. As our emphasis is on the entrainment of upper pycnocline waters, the ADCP is in an upward-looking configuration at 126 m, using 4 m bins. To provide near-surface velocity (where the ADCP estimates would not be reliable) we employ two Next Generation Vector Measuring Current Meters (NGVM). The nominal mooring design is a balance between resolving extremes versus typical annual cycling of the mixed layer.
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 2012

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Depth Range (m)</th>
<th>Analytical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Continuous Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth (Pressure)</td>
<td>0-4750</td>
<td>Pressure transducer on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Temperature</td>
<td>0-4750</td>
<td>Thermistor on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Conductivity (Salinity)</td>
<td>0-4750</td>
<td>Conductivity sensor on Sea-Bird CTD package, with discrete salinity samples calibration</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>0-4750</td>
<td>Sea-Bird sensor on Sea-Bird CTD package, with discrete oxygen samples calibration</td>
</tr>
<tr>
<td>Fluorescence (Chloropigment)</td>
<td>0-4750</td>
<td>Sea-Point chlorophyll fluorometer on Sea-Bird CTD package with discrete chlorophyll calibration</td>
</tr>
<tr>
<td>Nitrate</td>
<td>0-1000</td>
<td>Satlantic’s In Situ Ultraviolet Spectrophotometer (ISUS)</td>
</tr>
<tr>
<td><strong>II. Water Column Chemical Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>0-4750</td>
<td>Guildline AutoSal using Wormley seawater standard</td>
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<td>Oxygen</td>
<td>0-4750</td>
<td>Winkler titration</td>
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<td>Dissolved Inorganic Carbon</td>
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<td>Coulometry</td>
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<td>Total Alkalinity</td>
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<td>Automated Gran titration</td>
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<td>pH</td>
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<td>Spectrophotometric</td>
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<td>Nitrate Plus Nitrite</td>
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<td>Autoanalyzer</td>
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<tr>
<td>Soluble Reactive Phosphorus (SRP)</td>
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<td>Silicate</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
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<tr>
<td>Low Level [Nitrate + Nitrite]</td>
<td>0-200</td>
<td>Chemiluminescence</td>
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<tr>
<td>Low Level SRP</td>
<td>0-200</td>
<td>Magnesium-induced coprecipitation</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>0-4750</td>
<td>High temperature catalytic oxidation</td>
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<tr>
<td>Particulate Carbon</td>
<td>0-350</td>
<td>High temperature combustion</td>
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<tr>
<td>--------------------</td>
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</tr>
<tr>
<td>Particulate Nitrogen</td>
<td>0-350</td>
<td>High temperature combustion</td>
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<td>Particulate Phosphorus</td>
<td>0-350</td>
<td>High temperature combustion</td>
</tr>
<tr>
<td>Particulate Silica</td>
<td>0-175</td>
<td>Base Hydrolysis</td>
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</table>

### III. Biomass Measurements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll $a$ and Pheopigments</td>
<td>0-175</td>
<td>Fluorometric analysis using 10-AU</td>
</tr>
<tr>
<td>Pigments</td>
<td>0-175</td>
<td>High Performance Liquid Chromatography (HPLC)</td>
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<td>Bacteria and Cyanobacteria</td>
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<td>Nanoplankton and Microplankton</td>
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<td>Epi-fluorescence Microscopy</td>
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### IV. Carbon Assimilation and Particle Flux

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

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<td>Hull mounted, RDI #WH-300</td>
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<td>Hull mounted, RDI #NB-150</td>
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### VI. Optical Measurements

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<tr>
<td>Incident Irradiance</td>
<td>Surface</td>
<td>LI-COR LI-1000 &amp; Satlantic HyperOCR Hyperspectral Radiometer</td>
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<tr>
<td>Surface Upwelling Radiance and Downwelling Irradiance</td>
<td>Surface</td>
<td>Satlantic OCR 500 Multispectral Radiometers</td>
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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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<tr>
<td>Absorption and Beam Attenuation</td>
<td>0-200</td>
<td>WET Labs AC-9 &amp; AC-S connected to Sea-Bird CTD package</td>
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<tr>
<td>Fast Repetition Rate Fluorometry</td>
<td>0-200</td>
<td>Chelsea FAST$^{\text{track}}$ Dynamic Photosynthetic Fluorometer</td>
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<tr>
<td>Particle Size Analysis</td>
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<td>Sequoia Laser In-Situ Scattering &amp; Transmissometry (LISST-100X)</td>
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VII. Bow Intake System

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<th>Parameter</th>
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<tr>
<td>Temperature</td>
<td>Sea-Bird remote temperature sensor</td>
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<tr>
<td>Conductivity (Salinity)</td>
<td>Sea-Bird temperature and conductivity sensors inside the thermosalinograph</td>
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<td>Fluorometry (Chloropigment)</td>
<td>Fluorometric analysis using 10-AU</td>
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VIII. Moored Instruments

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<th>Instrument</th>
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<td>Sequencing Sediment Traps</td>
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<td>Parflux MK7-21</td>
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<td>Physical Oceanographic Mooring</td>
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These selected measurements are part of a much larger HOT program data set on physical and biogeochemical variability at Station ALOHA that has been collected since October 1988. The complete data set is available to the community by several methods that are described in Section 8.0 of this report.

This report presents selected core data collected during the 24th full year of the HOT Program (January-December 2012). During this period, ten regular 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-8 mooring instruments (July 2011 through June 2012), and during the mooring recovery cruise (WHOTS-9) 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 54 HOT staff, students and visiting scientists (Table 1.5) in our 2012 field work.

Table 1.4: Chronology of 2012 HOT Cruises

<table>
<thead>
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<th>Ship</th>
<th>Depart</th>
<th>Return</th>
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<td>17 January 2012</td>
<td>21 January 2012</td>
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<tr>
<td>240</td>
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<td>23 March 2012</td>
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<td>241</td>
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<td>R/V KOK</td>
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<td>2 June 2012</td>
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<tr>
<td>WHOTS-9</td>
<td>R/V Hi'ialakai</td>
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<td>25 June 2012</td>
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<td>30 July 2012</td>
<td>3 August 2012</td>
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<td>247</td>
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<td>6 October 2012</td>
<td>10 October 2012</td>
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<td>248</td>
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<td>6 December 2012</td>
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</table>
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 2012 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 2012.

CTD casts were made at Stations Kahe and ALOHA during each 2012 cruise. A CTD cast to 1000 m was made at Station Kahe during all the cruises.

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. Cruise 240 only had eleven casts and did not complete the 36 hour CTD burst period because of bad weather and problems with the CTD crane/winch system. Cruise 241 CTD burst period was interrupted for about 18 hours because of a medical emergency (see cruise report) One WOCE standard cast within 10 m of the bottom is made during each cruise. A second deep cast was obtained at this Station during every 2012 cruise except during HOT-240, and 241.

A CTD cast to 2400 m was conducted at Station Kaena during every 2012 cruise except HOT-241 and 242.

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 of at least five cycles were conducted during the 2012 cruises, except during HOT-241. Station 52 (22 40.15’N, 157 57.02’W) was occupied during HOT-239 through 242. After cruise 242, the WHOTS mooring was recovered and re-deployed to near the eastern edge of the ALOHA circle (Station 50: 22 46.07’N, 157 53.95’W). Station 50 was occupied during HOT-243, through 248 cruises.

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.
Salinity spike rejection parameters were modified for some cruises in 2012 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 239, 242, and 248, 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.

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.

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 is reported in \(\mu\)mol kg\(^{-1}\) and Chloropigment (Fluorescence) in μg/l.

### 2.1.2 Sensor Corrections and Calibrations

#### 2.1.2.1 Pressure

The pressure calibration strategy employed a high-quality quartz pressure transducer as a transfer standard. Periodic recalibrations of this 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.

##### 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 transducer #101430 was used during all 2012 cruises. 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 2012.

A 0.404 dbar correction was applied to the pressure offset at 0 dbar during data collection for all the 2012 casts conducted with sensor #101430 (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 0.404 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 throughout the year (0.12 dbar) is about 0.21 dbar higher than the mean 0 dbar offset from the February, August 2012, and January 2013 calibrations (-0.09 dbar, Table 2.1a). The cause of this difference is 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. Also, the before-cast pressures (Figure 2.1) show a decrease of about 0.15 dbar between the beginning and end of 2012, comparable to our 0 dbar pressure calibrations, which show a decrease of about 0.17 dbar throughout the year (Table 2.1a).

Table 2.1b indicates that the 0-dbar pressure for sensor #75434 remained fairly constant during 2012, with a slight increase of 0.04 dbar between February 2012 and January 2013.

The mean difference of between before-cast and an after-cast on-deck pressure for sensor #101430 during 2012 cruises (Figure 2.1) was 0.12 dbar, slightly larger than the hysteresis measured in the lab (0.09 dbar, Table 2.1a). The mean hysteresis measured during the 2012 bench tests for sensor #75434 was about 0.08 dbar (Table 2.1b).

The 0-4500 dbar pressure offset and hysteresis from the bench tests have been within expected values and nearly constant for the two sensors. A linear pressure dependent offset is applied during data collection for sensor #101430, to correct for the 0-4500 dbar span offset of about 1.22 dbar (Table 2.1a), which remained nearly constant during 2012.

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>
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</thead>
<tbody>
<tr>
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<td>-0.17</td>
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<td>0.09</td>
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<td>8 February 2012</td>
<td>0.00</td>
<td>1.19</td>
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<td>0.04</td>
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<td>0.10</td>
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Table 2.1b: CTD Pressure Calibrations against transfer standard. Units are decibars.

<table>
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<tr>
<th>Calibration Date</th>
<th>Offset @ 0 dbar</th>
<th>0-4500 dbar offset</th>
<th>Hysteresis</th>
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<td>24 July 2006</td>
<td>-0.24</td>
<td>0.53</td>
<td>0.17</td>
</tr>
<tr>
<td>24 August 2005</td>
<td>0.20</td>
<td>0.23</td>
<td>NA</td>
</tr>
<tr>
<td>17 February 2005</td>
<td>0.1</td>
<td>0.4</td>
<td>0.08</td>
</tr>
<tr>
<td>3 July 2004</td>
<td>0.49</td>
<td>0.17</td>
<td>0.05</td>
</tr>
<tr>
<td>9 February 2004</td>
<td>0.44</td>
<td>0.20</td>
<td>0.12</td>
</tr>
<tr>
<td>28 July 2003</td>
<td>0.45</td>
<td>0.12</td>
<td>0.15</td>
</tr>
<tr>
<td>5 February 2003</td>
<td>0.39</td>
<td>0.05</td>
<td>0.15</td>
</tr>
<tr>
<td>16 July 2002</td>
<td>0.43</td>
<td>0.15</td>
<td>0.1</td>
</tr>
<tr>
<td>28 January 2002</td>
<td>0.35</td>
<td>0.23</td>
<td>0.1</td>
</tr>
<tr>
<td>1 August 2001</td>
<td>0.1</td>
<td>-0.10</td>
<td>0.1</td>
</tr>
<tr>
<td>6 February 2001</td>
<td>0.24</td>
<td>-0.02</td>
<td>0.1</td>
</tr>
<tr>
<td>15 August 2000</td>
<td>0.18</td>
<td>0.12</td>
<td>0.1</td>
</tr>
<tr>
<td>13 January 2000</td>
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<td>0.13</td>
<td>0.08</td>
</tr>
<tr>
<td>24 June 1999</td>
<td>-0.03</td>
<td>0.20</td>
<td>0.1</td>
</tr>
</tbody>
</table>
2.1.2.2 Temperature

Two Sea-Bird SBE-3-Plus temperature transducers #1416 and #2454 were used during 2012 HOT cruises. These and our other three transducers #4448, #2907, and #5519 were calibrated at Sea-Bird on the dates indicated in Table 2.2. Sensor #5519 is a new sensor acquired in January 2012.


\[
\text{temperature} = \frac{1}{a + b \ln(f_0/f) + c \ln^2(f_0/f) + d \ln^3(f_0/f)} - 273.15
\]  (1)
Table 2.2: Calibration coefficients for Sea-Bird temperature sensors. RMS residuals from
calibration give an indication of quality of the calibration. Sensors #4073, and #1392 were used
in the thermosalinograph (Section 2.2).
SN
2454
2454
2454
2454
2454
2454

Date
yymmdd
130420
121221
120907
120511
120216
111208

f0

a

b

2885.22
2885.27
2885.31
2885.36
2885.37
2885.40

3.68121227e-03
3.68121226e-03
3.68121227e-03
3.68121173e-03
3.68121225e-03
3.68121094e-03

6.02207569e-04
6.02202954e-04
6.02196110e-04
6.02194844e-04
6.02188034e-04
6.02190055e-04

1.67735805e-05
1.67688028e-05
1.67816598e-05
1.67937787e-05
1.67634669e-05
1.67787094e-05

2.36654472e-06
2.36839058e-06
2.39435289e-06
2.40818966e-06
2.37714945e-06
2.39362837e-06

RMS
(m°C)
0.03
0.03
0.04
0.04
0.02
0.02

4448
4448
4448
4448
4448
4448
4448

130418
121221
120907
120512
120211
120106
111208

3075.57
3075.61
3075.54
3075.56
3075.55
3075.61
2872.26

3.68121378e-03
3.68121361e-03
3.68121359e-03
3.68121359e-03
3.68121369e-03
3.68121204e-03
3.68121086e-03

5.92722391e-04
5.92748025e-04
5.92710710e-04
5.92730047e-04
5.92719442e-04
5.92708270e-04
5.97067594e-04

1.49843929e-05
1.50354960e-05
1.49922423e-05
1.50364989e-05
1.50207226e-05
1.49830625e-05
1.50152706e-05

1.16294897e-06
1.20149801e-06
1.19329566e-06
1.22538392e-06
1.22197506e-06
1.18828350e-06
1.79746719e-06

0.09
0.07
0.08
0.07
0.08
0.07
0.04

2907
2907
2907
2907
2907
2907

130419
121221
120907
120512
120210
111208

3035.54
3035.55
3035.58
3035.51
3035.49
3035.51

3.68121311e-03
3.68121298e-03
3.68121236e-03
3.68121308e-03
3.68121252e-03
3.68121167e-03

5.99794584e-04
5.99788569e-04
5.99753233e-04
5.99778121e-04
5.99752376e-04
5.99759903e-04

1.59469432e-05
1.59268672e-05
1.58493043e-05
1.59317943e-05
1.58321091e-05
1.58985104e-05

2.12505661e-06
2.11083421e-06
2.06751835e-06
2.12727786e-06
2.02197087e-06
2.10548826e-06

0.09
0.08
0.03
0.07
0.09
0.10

1416
1416
1416
1416
1416
1416

130418
121221
120907
120512
120211
111208

6233.46
6233.51
6233.47
6233.55
6233.55
6233.66

3.68120966e-03
3.68120975e-03
3.68120979e-03
3.68121004e-03
3.68120995e-03
3.68120871e-03

6.01717330e-04
6.01723831e-04
6.01715632e-04
6.01736349e-04
6.01726937e-04
6.01722327e-04

1.46100832e-05
1.46108158e-05
1.46341513e-05
1.46939412e-05
1.46850658e-05
1.47288631e-05

1.78997011e-06
1.78360634e-06
1.81681657e-06
1.86140829e-06
1.86458252e-06
1.91968969e-06

0.28
0.28
0.28
0.24
0.28
0.27

5519
5519
5519
5519
5519
5519
5519
5519

140201
131106
130806
130418
121222
120906
120512
120217

3004.26
3004.26
3004.23
3004.28
3004.27
3004.24
3004.24
3004.23

3.68121327e-03
3.68121451e-03
3.68121296e-03
3.68121296e-03
3.68121327e-03
3.68121318e-03
3.68121292e-03
3.68121309e-03

5.90827337e-04
5.90896972e-04
5.90816769e-04
5.90834864e-04
5.90833374e-04
5.90826616e-04
5.90838747e-04
5.90831763e-04

1.48989111e-05
1.51213894e-05
1.48852058e-05
1.48967247e-05
1.48869620e-05
1.49005183e-05
1.49380321e-05
1.49229162e-05

1.56343849e-06
1.74135275e-06
1.53655316e-06
1.53354844e-06
1.52359138e-06
1.55385022e-06
1.58313788e-06
1.57198686e-06

0.07
0.07
0.06
0.06
0.07
0.06
0.05
0.06

1392
1392
1392
1392
1392
1392
1392
1392
1392
1392

121113
111026
100727
090627
070222
051007
040702
030603
020127
000127

2575.49
2575.46
2575.56
2575.44
2575.50
2575.57
2575.49
2575.48
2575.51
2575.59

3.64763754e-03
3.64763934e-03
3.64763687e-03
3.64763941e-03
3.64763736e-03
3.64763862e-03
3.64763908e-03
3.64763773e-03
3.64763443e-03
3.64763375e-03

5.86549938e-04
5.86547392e-04
5.86521549e-04
5.86529112e-04
5.86506823e-04
5.86558833e-04
5.86379560e-04
5.86506294e-04
5.86539063e-04
5.86545184e-04

9.43727458e-06
9.72572171e-06
9.37742942e-06
9.54439291e-06
9.42230158e-06
9.65295313e-06
9.00747869e-06
9.50040893e-06
9.55777980e-06
9.78001159e-06

-2.17145305e-06
-1.80489551e-06
-2.14857957e-06
-2.04471488e-06
-2.23128846e-06
-1.80339462e-06
-2.50476312e-06
-2.01054772e-06
-2.06798694e-06
-1.67704522e-06

0.14
0.43
0.18
0.39
0.12
0.34
0.38
0.32
0.12
0.20

4073
4073

121018
110322

2921.66
2921.70

3.68121215e-03
3.68121037e-03

6.01931433e-04
6.01925091e-04

1.56941407e-05
1.56879921e-05

1.91238228e-06
1.90518409e-06

0.01
0.03

25

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 2012 was less than $1.7 \times 10^{-3} \degree C$ 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 2012 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 2012 cruises, showing temperature differences within expected values. The mean temperature difference as a function of pressure was typically less than $1 \times 10^{-3} \degree C$, with a standard deviation of less than $0.5 \times 10^{-3} \degree C$ below 500 dbar. The largest variability was observed in the thermocline, with standard deviation values of up to $5 \times 10^{-3} \degree C$. 

Sensor #1416

This sensor has maintained a stable drift for a long time, and was used during all the 2012 cruises. The calibrations from February 2009 through April 2013 yielded a sensor drift of $3.80 \times 10^{-6} \degree C \text{ day}^{-1}$, with an intercept of $5.7 \times 10^{-4} \degree C$ and a RMS residual of $3.9 \times 10^{-4} \degree C$, which was used to obtain the drift correction for cruises HOT-239 through HOT-248, and WHOTS-9. When corrected for linear drift to 15 June 2012 (the mid-date when the sensor was used), the 12 May 2012 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 15 June 2012). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 0.8 m°C, and were applied to the data (Table 2.3).
Sensor #2454

The calibrations from September 2008 through April 2013 yielded a sensor drift of 4.85 x 10^{-6} °C day^{-1} with an intercept of 2.4 x 10^{-5} °C and a RMS residual of 5.2 x 10^{-4} °C, and was used to obtain the drift correction for cruises HOT-239 through HOT-248, and WHOTS-9. When corrected for linear drift to 15 June 2012 (the mid-date when the sensor was used), the 21 December 2012 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 15 June 2012). Drift corrections were obtained using this calibration as a baseline. The resulting drift corrections for each cruise were less than 1.7 m°C, and were applied to the data (Table 2.3).

Sensor #4448

This sensor was not used during 2012. The calibrations from January 2012 (after the sensor’s probe was replaced at Sea-Bird, see Fujieki et al., 2013) through April 2013 were used to estimate a sensor drift of 4.64 x 10^{-7} °C day^{-1} with an intercept of 5.1 x 10^{-4} °C and a RMS residual of 2.9 x 10^{-4} °C.

Sensor #2907

This sensor was not used during 2012. The calibrations from September 2009 through April 2013 indicated that the sensor had an offset in its calibration level after May 2012, and only the calibrations from September 2012 were used to calculate the sensor drift of 3.88 x 10^{-6} °C day^{-1} with an intercept of 9.9 x 10^{-5} °C and a RMS residual of 1.3 x 10^{-4} °C.

Sensor #5519

This sensor was newly acquired in January 2012, and it was not used during 2012. The calibrations from February 2012 through August 2013 were used to calculate the sensor drift of -2.63 x 10^{-7} °C day^{-1} with an intercept of 6.8 x 10^{-6} °C and a RMS residual of 2.1 x 10^{-5} °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-239</td>
<td>1416</td>
<td>-0.000433</td>
<td>2218</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-239</td>
<td>2454</td>
<td>-0.001634</td>
<td>3162</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-240</td>
<td>1416</td>
<td>-0.000182</td>
<td>2218</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-240</td>
<td>2454</td>
<td>-0.001314</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-241</td>
<td>1416</td>
<td>-0.000042</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-241</td>
<td>2454</td>
<td>-0.001135</td>
<td>2218</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-242</td>
<td>1416</td>
<td>0.000076</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-242</td>
<td>2454</td>
<td>-0.000984</td>
<td>2218</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-243</td>
<td>1416</td>
<td>0.000175</td>
<td>3162</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-243</td>
<td>2454</td>
<td>-0.000858</td>
<td>3984</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-244</td>
<td>1416</td>
<td>0.000308</td>
<td>3162</td>
<td>0.037</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-244</td>
<td>2454</td>
<td>-0.000689</td>
<td>3984</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-245</td>
<td>1416</td>
<td>0.000372</td>
<td>3162</td>
<td>0.028</td>
<td>S1,S6,S50; S2C1-7.9-15</td>
</tr>
<tr>
<td>HOT-245</td>
<td>2454</td>
<td>-0.000606</td>
<td>3984</td>
<td>0.020</td>
<td>S2C8-11</td>
</tr>
<tr>
<td>HOT-246</td>
<td>1416</td>
<td>0.000479</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-246</td>
<td>2454</td>
<td>-0.000470</td>
<td>3984</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-247</td>
<td>1416</td>
<td>0.000566</td>
<td>3162</td>
<td>0.028</td>
<td>All Casts</td>
</tr>
<tr>
<td>HOT-247</td>
<td>2454</td>
<td>-0.000359</td>
<td>2959</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-248</td>
<td>1416</td>
<td>0.000783</td>
<td>3162</td>
<td>0.037</td>
<td></td>
</tr>
<tr>
<td>HOT-248</td>
<td>2454</td>
<td>-0.000082</td>
<td>2959</td>
<td>0.020</td>
<td>All Casts</td>
</tr>
</tbody>
</table>

2.1.2.3 Conductivity

Four conductivity sensors were used during the 2012 cruises, #2218, #3162, #2959, and #3984. Sensor #3984 is a new sensor acquired in January 2012. Sensor #2218 failed during the first deep cast of HOT-239 and was replaced with sensor #2959, the sensor’s cell was found cracked by its center electrode and was repaired at Sea-Bird in March 2012. The history of the sensors is well documented in previous HOT data reports (Fujieki et al., 2014, 2013, 2012, 2010, 2008, 2007, 2006, 2005, Santiago-Mandujano et al., 2002, 2001, 1999, Tupas et al., 1993, 1994a, 1995, 1997, 1998, Karl et al. 1996). The dual sensor configurations are shown in Table 2.3. 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-239 through -248,
the standard deviation cutoff values for screening of bottle salinity samples were: 0.0034 (0-150 dbar), 0.0049 (151-500 dbar), 0.0019 (501-1050 dbar), and 0.0010 (1051-5000 dbar).

The conductivity calibration coefficients \((b_0, b_1, b_2)\) derived from the least squares fit \((\Delta C = b_0 + b_1C + b_2C^2)\) to the CTD-bottle conductivity differences \((\Delta C)\) as a function of conductivity \((C)\) are given in Table 2.4. Only cruises HOT-239 and -241 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>(b_0)</th>
<th>(b_1)</th>
<th>(b_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>2218</td>
<td>0.000603</td>
<td>-0.000223</td>
<td></td>
</tr>
<tr>
<td>HOT-239</td>
<td>3162</td>
<td>0.003420</td>
<td>-0.001680</td>
<td>0.000185</td>
</tr>
<tr>
<td>HOT-240</td>
<td>2218</td>
<td>0.000258</td>
<td>-0.000077</td>
<td></td>
</tr>
<tr>
<td>HOT-240</td>
<td>3162</td>
<td>0.001008</td>
<td>-0.000326</td>
<td></td>
</tr>
<tr>
<td>HOT-241</td>
<td>3162</td>
<td>0.000206</td>
<td>-0.000105</td>
<td></td>
</tr>
<tr>
<td>HOT-241</td>
<td>2218</td>
<td>0.006510</td>
<td>-0.003134</td>
<td>0.000318</td>
</tr>
<tr>
<td>HOT-242</td>
<td>3162</td>
<td>0.000328</td>
<td>-0.000162</td>
<td></td>
</tr>
<tr>
<td>HOT-242</td>
<td>2218</td>
<td>0.001232</td>
<td>-0.000525</td>
<td></td>
</tr>
<tr>
<td>HOT-243</td>
<td>3162</td>
<td>0.000041</td>
<td>-0.000211</td>
<td></td>
</tr>
<tr>
<td>HOT-243</td>
<td>3984</td>
<td>0.000551</td>
<td>-0.000286</td>
<td></td>
</tr>
<tr>
<td>HOT-244</td>
<td>3162</td>
<td>-0.000004</td>
<td>-0.000172</td>
<td></td>
</tr>
<tr>
<td>HOT-244</td>
<td>3984</td>
<td>0.000485</td>
<td>-0.000229</td>
<td></td>
</tr>
<tr>
<td>HOT-245</td>
<td>3162</td>
<td>-0.000017</td>
<td>-0.000176</td>
<td></td>
</tr>
<tr>
<td>HOT-245</td>
<td>3984</td>
<td>0.000380</td>
<td>-0.000223</td>
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</tr>
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<td>HOT-246</td>
<td>3162</td>
<td>0.000248</td>
<td>-0.000264</td>
<td></td>
</tr>
<tr>
<td>HOT-246</td>
<td>3984</td>
<td>0.000586</td>
<td>-0.000287</td>
<td></td>
</tr>
<tr>
<td>HOT-247</td>
<td>3162</td>
<td>0.000096</td>
<td>-0.000183</td>
<td></td>
</tr>
<tr>
<td>HOT-247</td>
<td>2959</td>
<td>-0.000104</td>
<td>-0.000005</td>
<td></td>
</tr>
<tr>
<td>HOT-248</td>
<td>3162</td>
<td>0.000038</td>
<td>-0.000200</td>
<td></td>
</tr>
<tr>
<td>HOT-248</td>
<td>2959</td>
<td>-0.000095</td>
<td>-0.000031</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.5: Individual cast conductivity corrections (units are Siemens m\(^{-1}\))

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Station</th>
<th>Cast</th>
<th>Correction</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>2</td>
<td>3</td>
<td>0.000009</td>
</tr>
<tr>
<td>HOT-239</td>
<td>2</td>
<td>16</td>
<td>0.000033</td>
</tr>
<tr>
<td>HOT-241</td>
<td>2</td>
<td>2</td>
<td>0.000077</td>
</tr>
<tr>
<td>HOT-242</td>
<td>2</td>
<td>2</td>
<td>0.000068</td>
</tr>
<tr>
<td>HOT-242</td>
<td>2</td>
<td>15</td>
<td>0.000059</td>
</tr>
<tr>
<td>HOT-243</td>
<td>2</td>
<td>14</td>
<td>0.000083</td>
</tr>
<tr>
<td>HOT-245</td>
<td>2</td>
<td>2</td>
<td>0.000027</td>
</tr>
<tr>
<td>HOT-245</td>
<td>2</td>
<td>15</td>
<td>0.000081</td>
</tr>
<tr>
<td>HOT-246</td>
<td>6</td>
<td>1</td>
<td>0.000171</td>
</tr>
<tr>
<td>HOT-248</td>
<td>2</td>
<td>2</td>
<td>0.000104</td>
</tr>
<tr>
<td>HOT-248</td>
<td>2</td>
<td>15</td>
<td>0.000097</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-239</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0022</td>
</tr>
<tr>
<td>HOT-239</td>
<td>3162</td>
<td>-0.0000</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-240</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-240</td>
<td>3162</td>
<td>-0.0002</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-241</td>
<td>3162</td>
<td>-0.0001</td>
<td>0.0014</td>
</tr>
<tr>
<td>HOT-241</td>
<td>2218</td>
<td>-0.0000</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-242</td>
<td>3162</td>
<td>-0.0001</td>
<td>0.0015</td>
</tr>
<tr>
<td>HOT-242</td>
<td>2218</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-243</td>
<td>3162</td>
<td>-0.0001</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-243</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0018</td>
</tr>
<tr>
<td>HOT-244</td>
<td>3162</td>
<td>-0.0000</td>
<td>0.0015</td>
</tr>
<tr>
<td>HOT-244</td>
<td>3984</td>
<td>-0.0001</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-245</td>
<td>3162</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-245</td>
<td>3984</td>
<td>-0.0002</td>
<td>0.0019</td>
</tr>
<tr>
<td>HOT-246</td>
<td>3162</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-246</td>
<td>3984</td>
<td>-0.0002</td>
<td>0.0019</td>
</tr>
<tr>
<td>HOT-247</td>
<td>3162</td>
<td>-0.0000</td>
<td>0.0019</td>
</tr>
<tr>
<td>HOT-247</td>
<td>2959</td>
<td>-0.0001</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-248</td>
<td>3162</td>
<td>0.0000</td>
<td>0.0015</td>
</tr>
<tr>
<td>HOT-248</td>
<td>2959</td>
<td>-0.0002</td>
<td>0.0013</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 2012.
2.1.2.4 Oxygen

During the 2012 cruises our four Sea-Bird SBE-43 oxygen sensors were used: #43262, #43918, #43982, and #431601. Sensor #431601 showed glitches during cruises HOT-247 and -248 and was sent to Sea-Bird for inspection, its SPAR glass sub assembly was found cracked and it was replaced in April 2013. The history of these sensors is documented in previous HOT data reports (Fujieki et al., 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).

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>0 to 1500 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>HOT-239</td>
<td>43918</td>
<td>0.00</td>
</tr>
<tr>
<td>HOT-240</td>
<td>43918</td>
<td>0.01</td>
</tr>
<tr>
<td>HOT-241</td>
<td>43918</td>
<td>-0.00</td>
</tr>
<tr>
<td>HOT-242</td>
<td>43918</td>
<td>0.00</td>
</tr>
<tr>
<td>HOT-243</td>
<td>43918</td>
<td>0.00</td>
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<tr>
<td>HOT-244</td>
<td>43918</td>
<td>-0.00</td>
</tr>
<tr>
<td>HOT-245</td>
<td>43918</td>
<td>-0.01</td>
</tr>
<tr>
<td>HOT-246</td>
<td>43918</td>
<td>0.01</td>
</tr>
<tr>
<td>HOT-247</td>
<td>43918</td>
<td>-0.00</td>
</tr>
<tr>
<td>HOT-248</td>
<td>43918</td>
<td>0.01</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>Mean</th>
<th>SD</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>43918</td>
<td>0.00</td>
<td>1.23</td>
<td>0.04</td>
<td>0.87</td>
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<tr>
<td>HOT-240</td>
<td>43918</td>
<td>-0.01</td>
<td>0.36</td>
<td>-0.01</td>
<td>0.38</td>
</tr>
<tr>
<td>HOT-241</td>
<td>43918</td>
<td>0.02</td>
<td>0.73</td>
<td>-0.02</td>
<td>0.69</td>
</tr>
<tr>
<td>HOT-242</td>
<td>43918</td>
<td>0.01</td>
<td>0.68</td>
<td>-0.02</td>
<td>0.63</td>
</tr>
<tr>
<td>HOT-243</td>
<td>43918</td>
<td>0.01</td>
<td>1.30</td>
<td>0.02</td>
<td>1.13</td>
</tr>
<tr>
<td>HOT-244</td>
<td>43918</td>
<td>0.05</td>
<td>1.06</td>
<td>0.12</td>
<td>0.75</td>
</tr>
<tr>
<td>HOT-245</td>
<td>43918</td>
<td>0.01</td>
<td>0.91</td>
<td>-0.05</td>
<td>0.75</td>
</tr>
<tr>
<td>HOT-246</td>
<td>43918</td>
<td>0.01</td>
<td>0.91</td>
<td>-0.02</td>
<td>0.65</td>
</tr>
<tr>
<td>HOT-247</td>
<td>43918</td>
<td>0.01</td>
<td>0.69</td>
<td>-0.01</td>
<td>0.57</td>
</tr>
<tr>
<td>HOT-248</td>
<td>43918</td>
<td>0.01</td>
<td>0.78</td>
<td>0.01</td>
<td>0.74</td>
</tr>
</tbody>
</table>

2.1.2.5 Fluorescence (Chloropigment)

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

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 bottle samples of each cruise to detect drift in the salinometer. Standard deviations of the secondary standard measurements were less than ± 0.0005 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 2012. Secondary Standard Batch #52 was created on December 22nd, 2011. Batch #53 was created on April 17th, 2012.
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>
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</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>34.4932±0.0004</td>
<td>15</td>
<td>52</td>
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</tr>
<tr>
<td>HOT-240</td>
<td>34.4926±0.0004</td>
<td>15</td>
<td>52</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-241</td>
<td>34.4934±0.0003</td>
<td>10</td>
<td>52</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-242</td>
<td>34.4919±0.0001</td>
<td>16</td>
<td>52</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-243</td>
<td>34.4929±0.0003</td>
<td>13</td>
<td>52</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-244</td>
<td>34.4926±0.0004</td>
<td>12</td>
<td>52</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-245</td>
<td>34.4919±0.0003</td>
<td>17</td>
<td>53</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-246</td>
<td>34.4914±0.0002</td>
<td>15</td>
<td>53</td>
<td>P153</td>
</tr>
<tr>
<td>HOT-247</td>
<td>34.4912±0.0004</td>
<td>14</td>
<td>53</td>
<td>P153</td>
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<tr>
<td>HOT-248</td>
<td>34.4907±0.0004</td>
<td>15</td>
<td>53</td>
<td>P153</td>
</tr>
</tbody>
</table>

2.2 Thermosalinograph

2.2.1 Data Acquisition

Continuous near-surface salinity and temperature data were collected during every 2012 HOT cruise (HOT-239 through HOT-248) using Sea-Bird thermosalinograph and temperature sensors aboard 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 2012 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: 2012 HOT Cruise Thermosalinograph Sensors

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Sensor S/N</th>
<th>Remote T</th>
<th>SBE-21 Internal T and C</th>
<th>SBE-45 Internal T and C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>KOK</td>
<td></td>
<td>4073</td>
<td>1392</td>
<td>-</td>
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<tr>
<td>HOT-240</td>
<td>KM</td>
<td></td>
<td>0169</td>
<td>-</td>
<td>0218</td>
</tr>
<tr>
<td>HOT-241</td>
<td>KOK</td>
<td></td>
<td>4073</td>
<td>1392</td>
<td>-</td>
</tr>
<tr>
<td>HOT-242</td>
<td>KOK</td>
<td></td>
<td>4073</td>
<td>1392</td>
<td>-</td>
</tr>
<tr>
<td>HOT-243</td>
<td>KM</td>
<td></td>
<td>0396</td>
<td>-</td>
<td>0267</td>
</tr>
<tr>
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<tr>
<td>HOT-246</td>
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<td>0396 to 0150</td>
<td>-</td>
<td>0267</td>
<td></td>
</tr>
<tr>
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<td>KM</td>
<td>0150</td>
<td>-</td>
<td>0267</td>
<td></td>
</tr>
<tr>
<td>HOT-248</td>
<td>KM</td>
<td>0150</td>
<td>-</td>
<td>0267</td>
<td></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 during consisted of 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 temperature sensor were acquired every 10 seconds. Data from the SBE-45 thermosalinograph were acquired every one second and during the processing stage were down-sampled in order to compare with the 10 second temperature data. These data were processed and calibrated against bottled salinity samples. Final data for 2012 from cruises in the R/V Kilo Moana are derived from the SBE-45 thermosalinograph at 10 second intervals. Higher resolution salinity data are available upon request.

The external temperature sensor in the R/V Kilo Moana was situated just aft of the seawater intake pump and the resultant water temperatures were found to be consistently higher than values obtained with the CTD at the same depth, apparently due to heating from the pump. External temperature data except for HOT-239, 241, and 242 (conducted on board the R/V Ka'imikai-O-Kanaloa) were adjusted using the 8 dbar CTD temperature data and subsequently flagged as un-calibrated.

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 10 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). Since sensors #4073 and #1392, are the same type as used for the CTD measurements, the same procedure for drift estimation was followed (see Section 2.1.2.2).

A temperature drift rate of 1.96 x 10⁻⁶ °C day⁻¹ was determined for remote temperature sensor #4073 using the calibrations in Table 2.2. Temperatures were calculated with the 22 March 2011 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are less than 0.9 x 10⁻³ °C and inconsequential.

A temperature drift rate of 3.847 x 10⁻⁷ °C day⁻¹ was determined for remote temperature sensor #1392 using the calibrations in Table 2.2. Temperatures were calculated with the 26 October 2011 baseline calibration. Drift corrections were not applied to the data for this sensor, as they were less than 1 x 10⁻⁴ °C.

Internal temperature sensors #218 and #267 are an SBE-45 model, and external temperature sensors #169, #0150, and #0396 are an SBE-38 model. These sensors use the following equation to convert the instrument output (n) to temperature (in °C):

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

A temperature drift rate of 8.78 x 10⁻¹⁰ °C day⁻¹ was determined for internal temperature sensor #218 using the calibrations in Table 2.10. Temperatures were calculated with the 4 May 2011 baseline calibration. Drift corrections were not applied to the data for this sensor, as they were less than 0.1 x 10⁻⁴ °C.

A temperature drift rate of -5.87 x 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 February 2012 baseline calibration. Drift corrections were not applied to the data for this sensor, as they were less than 2 x 10⁻⁴ °C.

A temperature drift rate of 2.03 x 10⁻⁷ °C day⁻¹ was determined for external temperature sensor #169 using the calibrations in Table 2.10. Temperatures were calculated with the 10 March 2010 baseline calibration. Drift correction was not applied to the data for this sensor, as it was less than 2 x 10⁻⁴ °C.
A temperature drift rate of $2.60 \times 10^{-7}^\circ C$ day$^{-1}$ was determined for external temperature sensor #0150 using the calibrations in Table 2.10. Temperatures were calculated with the 12 February 2012 baseline calibration. Drift corrections were not applied to the data for this sensor, as they were less than $0.8 \times 10^{-4}^\circ C$.

A temperature drift rate of $1.15 \times 10^{-7}^\circ C$ day$^{-1}$ was determined for external temperature sensor #0396 using the calibrations in Table 2.10. Temperatures were calculated with the 18 October 2011 baseline calibration. Drift corrections were not applied to the data for this sensor, as they were less than $0.4 \times 10^{-4}^\circ C$.

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$^\circ C$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>218</td>
<td>121121</td>
<td>-3.27708300e-05</td>
<td>2.81189400e-04</td>
<td>-2.86199800e-06</td>
<td>1.63990000e-07</td>
<td>0.10</td>
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<tr>
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<td>-2.54741500e-06</td>
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<td>169</td>
<td>70510</td>
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<td>50225</td>
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<td>2.78315700e-04</td>
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<td>30228</td>
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<td>2.80134900e-04</td>
<td>-2.67428900e-06</td>
<td>1.68445200e-07</td>
<td>0.03</td>
</tr>
</tbody>
</table>
2.2.2.1.2 Conductivity

Three different conductivity sensors were used to collect thermosalinograph data for the 2012 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 12 gross errors detected in temperature and no gross errors detected in conductivity during the ten 2012 HOT cruises. A typical cruise aboard R/V Ka’imikai-O-Kanaloa contained approximately 29,000 - 33,000 10-sec interval data points and on R/V Kilo Moana cruises it was approximately 325,000 – 335,000 1-sec interval data points. The remaining data were subsequently screened for bad or suspicious points and were ascribed to factors such as air bubbles entering the thermosalinograph system, low flow rate, electrical surges from the power supply, biological fouling of the thermosalinograph, 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 conductivity 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 280 to 14,000, with the majority of the flags being applied to the conductivity data. For the majority of cruises sections of flagged data were relatively small and were usually associated with air bubbles entering the thermosalinograph system during rough weather. Strong winds and rough seas particularly around Kaena Point during transit to ALOHA can introduce bubbles resulting in suspect data. Other flagged data were a result of insufficient time allowed for flushing of the uncontaminated seawater line before logging was commenced.

There were some specific problems encountered during the 2012 cruises which often resulted in sections of data being flagged and are summarized below:

- **HOT-239**: A large section of noisy temperature and conductivity data was observed on January 19th and 20th, 2012. The cause of the noise is unknown.

- **HOT-240**: A drift in thermosalinograph conductivity was observed during cruise. The sensor was swapped for the next cruise, yet the drift continued. A plumbing issue was believed to be the problem.
• **HOT-241**: There was a leak in the thermosalinograph system, discovered after HOT-242, that was attributed to the large noise estimates

• **HOT-242**: The thermosalinograph leak was discovered during the beginning of the cruise, but wasn’t fixed until after the cruise was completed.

• **HOT-243**: High temperature noise and a drift in thermosalinograph conductivity are attributed to the same plumbing issue in HOT-240

• **HOT-244**: Same problems as during HOT-240, HOT-243.

• **HOT-245**: Same problems as during HOT-240, HOT-243, HOT-244.

• **HOT-246**: A valve involved with the external temperature sensor, most likely closed before HOT-246, was attributed to questionable data collected on the cruise. This plumbing issue was corrected before HOT-248. Internal temperatures were reported for this cruise (see Section 2.2.2.4).

• **HOT-247**: Same issue as during HOT-246

• **HOT-248**: High rainfall was attributed to large spikes observed in temperature and conductivity data during the cruise.

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-239 through HOT-248 (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-239</td>
<td>0.0009</td>
<td>0.0024</td>
</tr>
<tr>
<td>HOT-240</td>
<td>0.0132</td>
<td>0.0006</td>
</tr>
<tr>
<td>HOT-241</td>
<td>0.0032</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-242</td>
<td>0.0015</td>
<td>0.0038</td>
</tr>
<tr>
<td>HOT-243</td>
<td>0.0006</td>
<td>0.0085</td>
</tr>
<tr>
<td>HOT-244</td>
<td>0.0004</td>
<td>0.0093</td>
</tr>
<tr>
<td>HOT-245</td>
<td>0.0006</td>
<td>0.0035</td>
</tr>
<tr>
<td>HOT-246</td>
<td>0.0004</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-247</td>
<td>0.0014</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-248</td>
<td>0.0005</td>
<td>0.0032</td>
</tr>
</tbody>
</table>
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 area aboard the two ships used in 2012 was located close to or directly next to the thermosalinograph used to calculate salinity. Thermosalinograph data were extracted within ±15 seconds around the bottle sample time.

As in previously reported cruises (Tupas et al., 1997) a cubic spline was fit to the time-series of the differences between the bottle conductivity and the thermosalinograph conductivity separately for all the 2012 HOT cruises. The correction of the thermosalinograph conductivities was obtained from this fit. Salinity was calculated using these corrected conductivities, thermosalinograph temperatures, and the pressure of the pump. The mean values for the salinity bottle minus final calibrated thermosalinograph were less than ±6 x 10^-6 for all cruises, with standard deviations shown in Table 2.12.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>1392</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-240</td>
<td>0218</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-241</td>
<td>1392</td>
<td>0.0035</td>
</tr>
<tr>
<td>HOT-242</td>
<td>1392</td>
<td>0.0043</td>
</tr>
<tr>
<td>HOT-243</td>
<td>0267</td>
<td>0.0026</td>
</tr>
<tr>
<td>HOT-244</td>
<td>0267</td>
<td>0.0011</td>
</tr>
<tr>
<td>HOT-245</td>
<td>0267</td>
<td>0.0006</td>
</tr>
<tr>
<td>HOT-246</td>
<td>0267</td>
<td>0.0006</td>
</tr>
<tr>
<td>HOT-247</td>
<td>0267</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-248</td>
<td>0267</td>
<td>0.0013</td>
</tr>
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</table>

The external temperature and the calibrated thermosalinograph salinity data collected during CTD casts were compared with the downcast CTD salinity from 4 dbar (R/V Ka‘imikai-O-Kanaloa cruises) and 8 dbar (R/V Kilo Moana cruises) as an additional quality control. This procedure was conducted in the same manner as previously reported HOT cruises. The thermosalinograph data were averaged using data sampled one minute after the acquisition time of the CTD sample.
For cruises in the R/V *Kilo Moana*, all external temperature data (except HOT-246 and HOT-247 due to a closed valve) were corrected to allow for slight heating from the pump using the mean difference with that of the 8 dbar CTD temperature data (see Section 2.2.1). As a result final CTD temperature – external temperature values are zero (except HOT-246 and HOT-247). The offset is shown in Table 2.13. Mean thermostanligraph salinity difference with the CTD salinity were smaller than ±0.002 psu for all cruises. For cruises HOT-246 and HOT-247, internal temperatures were reported instead of external temperatures, after correcting using the 8 dbar CTD temperatures.

Table 2.13: *CTD - External Temperature and CTD – Thermostaligraph Salinity*

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ext T Sensor #</th>
<th>CTD-External Temperature (ºC)</th>
<th>Offset Applied (ºC)</th>
<th>SBE-21 Sensor #</th>
<th>SBE-45 Sensor #</th>
<th>CTD-Thermosal Salinity (psu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-239</td>
<td>4073</td>
<td>-0.00228</td>
<td>-</td>
<td>1392</td>
<td>-</td>
<td>0.000162</td>
</tr>
<tr>
<td>HOT-240</td>
<td>0169</td>
<td>0.0000*</td>
<td>-0.41485</td>
<td>-</td>
<td>0218</td>
<td>0.000925</td>
</tr>
<tr>
<td>HOT-241</td>
<td>4073</td>
<td>-0.00323</td>
<td>-0.00323</td>
<td>1392</td>
<td>-</td>
<td>0.000939</td>
</tr>
<tr>
<td>HOT-242</td>
<td>4073</td>
<td>-0.00054</td>
<td>-</td>
<td>1392</td>
<td>-</td>
<td>0.000739</td>
</tr>
<tr>
<td>HOT-243</td>
<td>0396</td>
<td>0.0000*</td>
<td>-</td>
<td>-</td>
<td>0267</td>
<td>-0.002926</td>
</tr>
<tr>
<td>HOT-244</td>
<td>0396</td>
<td>0.0000*</td>
<td>-0.44399</td>
<td>-</td>
<td>0267</td>
<td>0.000847</td>
</tr>
<tr>
<td>HOT-245</td>
<td>0396</td>
<td>0.0000*</td>
<td>-0.46592</td>
<td>-</td>
<td>0267</td>
<td>0.000437</td>
</tr>
<tr>
<td>HOT-246</td>
<td>0150</td>
<td>-0.31620**</td>
<td>-</td>
<td>-</td>
<td>0267</td>
<td>0.000171</td>
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<tr>
<td>HOT-247</td>
<td>0150</td>
<td>-0.73640**</td>
<td>-</td>
<td>-</td>
<td>0267</td>
<td>-0.002238</td>
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<tr>
<td>HOT-248</td>
<td>0150</td>
<td>0.0000*</td>
<td>-0.28556</td>
<td>-</td>
<td>0267</td>
<td>-0.001993</td>
</tr>
</tbody>
</table>

*after offset applied
**no offset applied due to bad data from sensor. Internal sensor temperatures were reported instead (see text).

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 Guge and RM Young), these data were compared against the measurements taken by the WHOTS buoy (see Section 4.10). In addition, a RM Young Ultrasonic anemometer was installed on the ship before cruise HOT-243.

2.4 ADCP Measurements

Currents in the upper ocean (0-1200 m) during 2012 were measured using shipboard Acoustic Doppler Current Profilers (ADCP) on board R/V Kilo Moana. The ADCP system aboard R/V Ka'imikai-O-Kanaloa was inoperable during HOT cruises conducted in 2012.

ADCP data on board R/V Kilo Moana are collected and preliminarily processed 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 Work Horse 300 is located on the port side both with 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 Work Horse (WH300) operates at 300 kHz profiling typically 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.

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 during HOT-240, 243, 244, 246 and 247 were processed without any reported incidents. HOT-
245 ADCP data had to be reconverted from raw data during final processing due to read errors of improperly closed data files during initial processing. The WH300 was inoperable during HOT-248 making only OS38BB and OS38NB data available for the cruise.

The inoperable ADCP system onboard R/V Kaʻimikai-O-Kanaloa resulted in no ADCP data being available for HOT-239, HOT-241 and HOT-242.

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 2012.

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.

Precision of the Winkler titration method is presented in Table 2.14. The pooled annual mean CV of our oxygen analyses in 2012 was 0.21 %, which was calculated by averaging the mean CV of N-triplicate samples on each cruise. Oxygen concentrations measured over the 24 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 24 years of the HOT program.
Table 2.14: Precision of Winkler titration method during 2012

<table>
<thead>
<tr>
<th>HOT</th>
<th>Dissolved O₂</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µmol kg⁻¹)</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td>0.15</td>
<td>0.258</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>0.17</td>
<td>0.303</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>0.24</td>
<td>0.452</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>242</td>
<td>0.17</td>
<td>0.323</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>243</td>
<td>0.17</td>
<td>0.280</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>244</td>
<td>0.21</td>
<td>0.398</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>245</td>
<td>0.33</td>
<td>0.560</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>0.26</td>
<td>0.506</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>247</td>
<td>0.21</td>
<td>0.373</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>0.20</td>
<td>0.364</td>
<td>8</td>
<td></td>
</tr>
</tbody>
</table>
| Mean| **0.21**     | **0.382**                  | **10**
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.
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 2012 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 2012 was 0.06 % (Table 2.15).

Table 2.15: Precision of DIC and Total Alkalinity analyses during 2012

<table>
<thead>
<tr>
<th>HOT</th>
<th>DIC</th>
<th></th>
<th></th>
<th></th>
<th>Talk</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µmol kg⁻¹)</td>
<td>N</td>
<td>Mean CV (%)</td>
<td>Mean SD (µeq kg⁻¹)</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>239</td>
<td>0.03</td>
<td>0.599</td>
<td>3</td>
<td>0.07</td>
<td>1.579</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>240</td>
<td>0.01</td>
<td>0.170</td>
<td>3</td>
<td>0.03</td>
<td>0.601</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>241</td>
<td>0.02</td>
<td>0.507</td>
<td>3</td>
<td>0.07</td>
<td>1.579</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>242</td>
<td>0.00</td>
<td>0.090</td>
<td>3</td>
<td>0.08</td>
<td>1.862</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>243</td>
<td>0.01</td>
<td>0.295</td>
<td>3</td>
<td>0.11</td>
<td>2.569</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>244</td>
<td>0.02</td>
<td>0.403</td>
<td>3</td>
<td>0.07</td>
<td>1.662</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>245</td>
<td>0.01</td>
<td>0.212</td>
<td>3</td>
<td>0.08</td>
<td>1.980</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>246</td>
<td>0.02</td>
<td>0.462</td>
<td>3</td>
<td>0.07</td>
<td>1.556</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>247</td>
<td>0.01</td>
<td>0.120</td>
<td>3</td>
<td>0.04</td>
<td>0.813</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>248</td>
<td>0.11</td>
<td>2.197</td>
<td>3</td>
<td>0.02</td>
<td>0.519</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.506</td>
<td>10</td>
<td>0.06</td>
<td>1.472</td>
<td>10</td>
<td></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.
2.5.3 pH

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

The pooled annual CV of the pH analysis during 2012 was 0.020 (Table 2.16). It was calculated by averaging the mean CV of N-duplicate samples on each cruise. The time-series of measured values at 4500 decibars at Station ALOHA are shown in Figure 2.6.

Table 2.16: Precision of pH analyses during 2012

<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>239</td>
<td>0.022</td>
<td>0.0018</td>
<td>4</td>
</tr>
<tr>
<td>240</td>
<td>0.009</td>
<td>0.0007</td>
<td>4</td>
</tr>
<tr>
<td>241</td>
<td>0.045</td>
<td>0.0036</td>
<td>4</td>
</tr>
<tr>
<td>242</td>
<td>0.007</td>
<td>0.0006</td>
<td>4</td>
</tr>
<tr>
<td>243</td>
<td>0.011</td>
<td>0.0009</td>
<td>3</td>
</tr>
<tr>
<td>244</td>
<td>0.025</td>
<td>0.0020</td>
<td>3</td>
</tr>
<tr>
<td>245</td>
<td>0.020</td>
<td>0.0016</td>
<td>4</td>
</tr>
<tr>
<td>246</td>
<td>0.012</td>
<td>0.0010</td>
<td>4</td>
</tr>
<tr>
<td>247</td>
<td>0.034</td>
<td>0.0027</td>
<td>4</td>
</tr>
<tr>
<td>248</td>
<td>0.014</td>
<td>0.0011</td>
<td>4</td>
</tr>
<tr>
<td>Mean</td>
<td>0.020</td>
<td>0.0016</td>
<td>10</td>
</tr>
</tbody>
</table>

Figure 2.6: pH measured at 4500 decibars at Station ALOHA. The mean (± stdev, n=28) 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 2012 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 24 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 2012

<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>239</td>
<td>0.10</td>
<td>0.003</td>
<td>6</td>
<td>0.30</td>
<td>0.056</td>
<td>7</td>
<td>0.11</td>
<td>0.140</td>
<td>6</td>
</tr>
<tr>
<td>240</td>
<td>1.30</td>
<td>0.033</td>
<td>6</td>
<td>1.18</td>
<td>0.413</td>
<td>6</td>
<td>2.30</td>
<td>1.510</td>
<td>6</td>
</tr>
<tr>
<td>241</td>
<td>0.64</td>
<td>0.018</td>
<td>6</td>
<td>0.69</td>
<td>0.239</td>
<td>6</td>
<td>2.07</td>
<td>1.159</td>
<td>5</td>
</tr>
<tr>
<td>242</td>
<td>0.30</td>
<td>0.008</td>
<td>6</td>
<td>0.15</td>
<td>0.057</td>
<td>6</td>
<td>0.11</td>
<td>0.145</td>
<td>6</td>
</tr>
<tr>
<td>243</td>
<td>0.29</td>
<td>0.008</td>
<td>6</td>
<td>1.18</td>
<td>0.081</td>
<td>7</td>
<td>0.21</td>
<td>0.303</td>
<td>6</td>
</tr>
<tr>
<td>244</td>
<td>0.13</td>
<td>0.003</td>
<td>6</td>
<td>0.22</td>
<td>0.055</td>
<td>7</td>
<td>0.14</td>
<td>0.188</td>
<td>6</td>
</tr>
<tr>
<td>245</td>
<td>0.20</td>
<td>0.006</td>
<td>6</td>
<td>0.15</td>
<td>0.058</td>
<td>6</td>
<td>0.16</td>
<td>0.201</td>
<td>6</td>
</tr>
<tr>
<td>246</td>
<td>0.15</td>
<td>0.004</td>
<td>6</td>
<td>0.12</td>
<td>0.047</td>
<td>6</td>
<td>0.14</td>
<td>0.192</td>
<td>6</td>
</tr>
<tr>
<td>247</td>
<td>0.27</td>
<td>0.007</td>
<td>7</td>
<td>0.18</td>
<td>0.065</td>
<td>7</td>
<td>0.26</td>
<td>0.370</td>
<td>6</td>
</tr>
<tr>
<td>248</td>
<td>0.09</td>
<td>0.002</td>
<td>6</td>
<td>0.37</td>
<td>0.058</td>
<td>7</td>
<td>0.71</td>
<td>0.814</td>
<td>6</td>
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<tr>
<td>Mean</td>
<td>0.35</td>
<td>0.009</td>
<td>10</td>
<td>0.45</td>
<td>0.113</td>
<td>10</td>
<td>0.62</td>
<td>0.502</td>
<td>10</td>
</tr>
</tbody>
</table>
Figure 2.7: Concentrations at potential density horizons of 27.782, 27.758 and 27.675 (approx. 4000m, 3000m and 2000m) at Station ALOHA. The dashed lines indicate the mean while the dotted lines show the upper and lower confidence limits. [Upper panel] Dissolved oxygen. [Lower panel] nitrate + nitrite.
Figure 2.8: Concentrations at potential density horizons of 27.782, 27.758 and 27.675 (approx. 4000m, 3000m and 2000m) at Station ALOHA. [Upper panel] Soluble reactive phosphorus. [Lower panel] Dissolved Silicate.
Calibration, Data Reduction and Calculations

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

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

Blank corrections

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

Quality Control

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

Both the Wako and OSIL standards are used as checks of not only the sample analysis, but as checks of each other. Measured reference material values that are more than 2% from the expected concentration of the reference solutions are scrutinized and cross checked with the other reference material to determine if the analysis is correct. In most cases, both reference materials are within the accepted limits.
Figure 2.9: Wako - 2.0 µM in NaCl, measured directly. Literature shows value of CSK can be up to ~7% low return, so concentration ~1.8 is acceptable. The mean (± stdev, n=150) was 1.889 ± 0.031 µM.

Figure 2.10: OSIL - 100 µM stock in DIW, diluted in LNSW to be 2 µM. The mean (± stdev, n=351) was 1.985 ± 0.022 µM.
Figure 2.11: Wako - 40.0 µM in NaCl, measured directly. The mean (± stdev, n=143) was 39.855 ± 0.277 µM.

Figure 2.12: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 40 µM. The mean (± stdev, n=288) was 39.880 ± 0.300 µM.
Figure 2.13: Wako - 100.0 µM in NaCl, measured directly. The mean (± stdev, n=166) was 100.469 ± 0.754 µM.

Figure 2.14: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 100 µM. The mean (± stdev, n=267) was 100.215 ± 0.509 µM.
Figure 2.15: Wako - 100.0 µM in NaCl, measured directly. The mean (± stdev, n=181) was 100.381 ± 0.748 µM.

Figure 2.16: OSIL - 1000 µM stock in DIW, diluted in LNSW to be 100 µM. The mean (± stdev, n=298) was 100.322 ± 0.611 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 Nitrate Quality Control Chart](image)

Figure 2.17: The mean (± stdev, n=40) was 4.11 ± 0.46 nmol L⁻¹.
Figure 2.18: The mean (± stdev, n=45) was 15.99 ± 1.02 nmol L⁻¹.

Figure 2.19: The mean (± stdev, n=40) was 158.68 ± 3.53 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=46) was 1.7 ± 2.6 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>
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<td>225</td>
<td>5.8</td>
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<td>226</td>
<td>7.2</td>
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<td>4</td>
</tr>
<tr>
<td>227</td>
<td>2.0</td>
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<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.
Figure 2.21: Values were obtained from DSRM from the RSMAS Consensus Reference Materials (CRM) Project. The accepted range of the DSRM is 41-44 µM. The DSRM is used to verify the standard dilution curve used to calibrate each sample run. The mean (± stddev, n=32) was 43.45 ± 1.38 µM.

2.5.6 Particulate Bioelements

2.5.6.1 Particulate Carbon and Nitrogen

Samples for elemental analyses of Particulate carbon (PC) and nitrogen (PN) were prefILTERED through 202 µm Nitex mesh to remove large zooplankton and collected onto combusted glass fiber filters (Whatman GF/F, 25 mm diameter). They were analyzed using an Exeter Analytical CE-440 CHN elemental analyzer. This instrument combines the classical Pregal and Dumas methods for the determination of PC and PN, respectively. The samples are combusted in pure 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 2012 are presented in Table 2.19. Figure 2.22 shows the time-series of our in-house plankton secondary standard. 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 2012

<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>239</td>
<td>3.5</td>
<td>0.697</td>
</tr>
<tr>
<td>240</td>
<td>8.7</td>
<td>1.658</td>
</tr>
<tr>
<td>241</td>
<td>10.0</td>
<td>2.224</td>
</tr>
<tr>
<td>242</td>
<td>21.3</td>
<td>7.545</td>
</tr>
<tr>
<td>243</td>
<td>3.9</td>
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<td>244</td>
<td>1.8</td>
<td>0.385</td>
</tr>
<tr>
<td>245</td>
<td>9.7</td>
<td>2.595</td>
</tr>
<tr>
<td>246</td>
<td>13.8</td>
<td>3.111</td>
</tr>
<tr>
<td>247</td>
<td>1.4</td>
<td>0.308</td>
</tr>
<tr>
<td>248</td>
<td>9.6</td>
<td>1.771</td>
</tr>
<tr>
<td>Mean</td>
<td>8.4</td>
<td>2.134</td>
</tr>
</tbody>
</table>

Figure 2.22: PC/PN ratios obtained using an in-house plankton secondary standard. The secondary standard is used to verify the independently made standard curve used in each analytical run. The mean (± stdev, n=149) was 4.83 ± 0.17.
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 2012 are presented in Table 2.20.

Table 2.20: Field variability of Particulate phosphorus analyses during 2012

<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>239</td>
<td>27.1</td>
<td>0.088</td>
<td>2</td>
</tr>
<tr>
<td>240</td>
<td>21.9</td>
<td>0.071</td>
<td>2</td>
</tr>
<tr>
<td>241</td>
<td>3.5</td>
<td>0.015</td>
<td>2</td>
</tr>
<tr>
<td>242</td>
<td>25.3</td>
<td>0.067</td>
<td>2</td>
</tr>
<tr>
<td>243</td>
<td>4.2</td>
<td>0.018</td>
<td>2</td>
</tr>
<tr>
<td>244</td>
<td>4.9</td>
<td>0.021</td>
<td>2</td>
</tr>
<tr>
<td>245</td>
<td>4.3</td>
<td>0.021</td>
<td>2</td>
</tr>
<tr>
<td>246</td>
<td>61.2</td>
<td>0.209</td>
<td>2</td>
</tr>
<tr>
<td>247</td>
<td>3.7</td>
<td>0.011</td>
<td>2</td>
</tr>
<tr>
<td>248</td>
<td>22.6</td>
<td>0.081</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>17.9</td>
<td>0.060</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.
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.
Figure 2.24b: Final concentrations for A) seawater (25 m) samples and B) apple leaf samples for treatments 1 (passive leach) and treatment 2 (vortexed and leached.) C) shows the absorbance values for blank filters over time, uncorrected for any dilutions.

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 PPO_4 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 2012 are presented in Table 2.21.

Table 2.21: Field variability of Particulate biogenic silica analyses during 2012

<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>239</td>
<td>58.0</td>
<td>2.952</td>
<td>2</td>
</tr>
<tr>
<td>240</td>
<td>8.9</td>
<td>1.750</td>
<td>2</td>
</tr>
<tr>
<td>241</td>
<td>38.1</td>
<td>6.668</td>
<td>2</td>
</tr>
<tr>
<td>242</td>
<td>9.8</td>
<td>1.736</td>
<td>2</td>
</tr>
<tr>
<td>243</td>
<td>16.2</td>
<td>3.136</td>
<td>2</td>
</tr>
<tr>
<td>244</td>
<td>10.1</td>
<td>1.704</td>
<td>2</td>
</tr>
<tr>
<td>245</td>
<td>9.2</td>
<td>1.545</td>
<td>2</td>
</tr>
<tr>
<td>246</td>
<td>6.7</td>
<td>1.397</td>
<td>2</td>
</tr>
<tr>
<td>248</td>
<td>31.9</td>
<td>4.434</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>21.0</td>
<td>2.814</td>
<td>9</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 2012 determined from triplicate analyses are presented in Table 2.22.

Table 2.22: Precision of Fluorometric Chlorophyll a and Pheopigment analyses during 2012

<table>
<thead>
<tr>
<th>HOT</th>
<th>Chlorophyll a</th>
<th>Pheopigments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µg l⁻¹)</td>
</tr>
<tr>
<td>239</td>
<td>4.2</td>
<td>0.008</td>
</tr>
<tr>
<td>240</td>
<td>11.7</td>
<td>0.019</td>
</tr>
<tr>
<td>241</td>
<td>6.4</td>
<td>0.009</td>
</tr>
<tr>
<td>242</td>
<td>5.9</td>
<td>0.009</td>
</tr>
<tr>
<td>243</td>
<td>5.6</td>
<td>0.006</td>
</tr>
<tr>
<td>244</td>
<td>6.3</td>
<td>0.007</td>
</tr>
<tr>
<td>245</td>
<td>4.2</td>
<td>0.005</td>
</tr>
<tr>
<td>246</td>
<td>3.4</td>
<td>0.004</td>
</tr>
<tr>
<td>247</td>
<td>3.9</td>
<td>0.006</td>
</tr>
<tr>
<td>248</td>
<td>4.6</td>
<td>0.006</td>
</tr>
<tr>
<td>Mean</td>
<td>5.6</td>
<td>0.008</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 2012 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 2012.
### Table 2.23: 2012 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>0.397</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>0.380</td>
<td>0.434</td>
</tr>
<tr>
<td>19'-Hexanoyloxyfucoxanthin</td>
<td>0.378</td>
<td>0.472</td>
</tr>
<tr>
<td>Prasinoxanthin</td>
<td>0.420</td>
<td>0.538</td>
</tr>
<tr>
<td>Violaxanthin</td>
<td>0.280</td>
<td>0.572</td>
</tr>
<tr>
<td>Diadinoxanthin</td>
<td>0.289</td>
<td>0.647</td>
</tr>
<tr>
<td>Alloxanthin</td>
<td>0.286</td>
<td>0.721</td>
</tr>
<tr>
<td>Lutein</td>
<td>0.297</td>
<td>0.797</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>0.318</td>
<td>0.812</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll b</td>
<td>0.970</td>
<td>0.938</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>1.176</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 = (c₁ + c₂ + c₃), Mg 3,8D = Mg 3,8 divinyl pheoporphyrin a₅ 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 2012. 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 2012 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 2012

<table>
<thead>
<tr>
<th>HOT</th>
<th>Particulate ATP</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (ng l⁻¹)</td>
<td>N</td>
</tr>
<tr>
<td>239</td>
<td>9.3</td>
<td>1.585</td>
<td>9</td>
</tr>
<tr>
<td>240</td>
<td>24.7</td>
<td>3.300</td>
<td>9</td>
</tr>
<tr>
<td>241</td>
<td>21.7</td>
<td>2.303</td>
<td>9</td>
</tr>
<tr>
<td>242</td>
<td>13.8</td>
<td>2.048</td>
<td>9</td>
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<tr>
<td>243</td>
<td>19.1</td>
<td>2.183</td>
<td>9</td>
</tr>
<tr>
<td>244</td>
<td>16.6</td>
<td>3.965</td>
<td>9</td>
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<tr>
<td>245</td>
<td>10.6</td>
<td>2.406</td>
<td>9</td>
</tr>
<tr>
<td>246</td>
<td>14.7</td>
<td>2.383</td>
<td>9</td>
</tr>
<tr>
<td>247</td>
<td>11.8</td>
<td>2.270</td>
<td>9</td>
</tr>
<tr>
<td>248</td>
<td>15.1</td>
<td>1.826</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>15.7</td>
<td>2.427</td>
<td>10</td>
</tr>
</tbody>
</table>

73
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 2012, 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 Surface Downwelling Irradiance and Upwelling Radiance

Downwelling irradiance and upwelling radiance at the sea-surface were measured using a pair of Satlantic OCR 500 Mutispectral radiometers that had been integrated into the bouy used in our free-floating particle flux array. Wavelengths measured are from 400 – 865 nm. Since the array is out for an approximately 60 h duration, an equivalent amount of light data could be collected.
2.7.4 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), a Chelsea Fast Repetition Rate Fluorometer (FRRf) 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 (justification given in Section 2.7.5). At least 2 back-to-back profiles were normally taken, one using a 0.2 \( \mu \)m 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.

2.7.5 Fast Repetition Rate Fluorometry (FRRf)

Day and night time FRRf profiles were made using a Chelsea FAST\(^{\text{tracka}}\) Dynamic Photosynthetic Fluorometer. The FRRf was part of an instrument package that also included a Sea-Bird CTD, a WET Labs ECO-BBF2 Triplet (measuring Chlorophyll, CDOM & Phycoerythrin), a WET Labs AC-9, a WET Labs AC-S and a Sequoia Laser In-Situ Scattering and Transmissometry (LISST-100X) instrument. The FRRf was oriented horizontally and lowered at a more-or-less constant speed of 10 m min\(^{-1}\) to a bottom depth of approximately 200 m. This speed was empirically determined to better resolve fluorescence response of small scale (~ 0.5m) photoautotrophic assemblages and to allow enough time for the gain switch of the instrument without losing significant vertical resolution (Corno \textit{et. al.} 2005). The sampling protocol of the FRRf was set to an acquisition sequence of 100 saturation flashes, 20 relaxation flashes and 10 m sec\(^{-1}\) sleep time between acquisitions. The flash duration was of 0.65 \( \mu \) sec (4 instrument units). This sampling protocol was found to better characterize the fluorescence response (i.e. saturation curve fitting) of this specific oceanic waters in preliminary tests (G. Corno unpublished data). Depth and \textit{in situ} irradiance (PAR) were also logged with each profile.

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

Forward light scattering can be used for rapid determination of \textit{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) \textit{in situ} data. The LISST-100X measures the near-forward angular scattering distribution between 0.0017 to 0.34 radians (0.097-19.48\(^{\circ}\); 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 \( \langle V(D_i) \rangle \) in units of mL L\(^{-1}\) for 32 logarithmically spaced size classes with geometric mean diameters \( \langle D_i \rangle \) 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 \textit{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 \( \langle A(D_i) \rangle \) is then calculated from the volume size distribution \( \langle V(D_i) \rangle \) by assuming spherical geometry: \( \langle A(D_i) \rangle = \frac{3}{2} \left\langle V(D_i) \right\rangle D_i^{-1} \). The mean particle size \( \langle D_{\text{AVG}} \rangle \), 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 \textit{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: \textit{Prochlorococcus}, \textit{Synechococcus} and the pico-Eukaryotes. Heterotrophic bacteria were enumerated using the DNA stain SYBR Green I and subtracting the previously obtained \textit{Prochlorococcus} concentration from the DNA positive cells.

For intra-analysis variance, one duplicate was analyzed from each HOT profile. Duplicates were selected by the operator to include deep and shallow sample types. \textit{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 Deep Chlorophyll Maximum (DCM) and beyond are easily resolved and the precision values on these counts more closely indicate instrument variability.

No adequate marine reference materials exist for flow cytometry so samples for estimating inter-analysis variations were collected during the summer when \textit{Prochlorococcus} fluorescence was dimmest. At least 80 samples were collected at Station ALOHA and preserved from both the DCM and 5 decibars. One of each was analyzed each day of analysis. Precision percentages were calculated for both depths for each cell-type (\textit{Figures 2.27} - 2.30).
Figure 2.27: Prochlorococcus measured at 5 decibars at Station ALOHA. The mean (± stdev, n=9) was $2.170 \times 10^5 \pm 0.174 \times 10^5$ # ml\(^{-1}\).

Figure 2.28: Prochlorococcus measured at the DCM at Station ALOHA. The mean (± stdev, n=9) was $4.134 \times 10^4 \pm 0.244 \times 10^4$ # ml\(^{-1}\).
Figure 2.29: Heterotrophic Bacteria measured at 5 decibars at Station ALOHA. The mean (± stdev, n=9) was $6.520e5 ± 0.697e5$ # ml$^{-1}$.

Figure 2.30: Heterotrophic Bacteria measured at the DCM at Station ALOHA. The mean (± stdev, n=9) was $3.271e5 ± 0.199e5$ # 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, dinoflagellages, 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: \( \pi * \text{length}^2 * \text{width}^2 * 6^{-1} \). 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 Brancner 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-m\textsuperscript{2} diameter ring net, with GO 2030R flow meter and Vemco minilog Time-Depth Recorder. Both frames are fitted with 202-µm filter mesh nets with similar aspect ratios, and they have roughly comparable mouth areas under tow. They are lowered to depth and returned to the surface similarly (by capstan). The main difference is a preceding bridle on the ring net, which may be easier to avoid by larger animals with fast escape responses compared to the side bridles of the original rectangular net. 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 m\textsuperscript{2} Isaacs-Kidd mid-water trawl and 96 m\textsuperscript{2} 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-8 mooring was deployed at Station 52: 22 40.15’N, 157 57.02’W, during the WHOTS-8 cruise (July 5-13, 2011) on board the R/V Hi’ialakai, collecting data from 7 July 2011 to 16 June 2012, and was recovered during the WHOTS-9 cruise (12-20 June, 2012) on board the R/V Hi’ialakai. Details of the instrumentation (Figure 2.31), and deployment are in the
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 15 Microcats (SeaBird SBE-37) deployed to record temperature and conductivity (C-T) at 15, 25, 35, 40, 45, 50, 55, 65, 75, 85, 95, 105, 120, 135 and 155 m. The Microcats at 45, 85, 105, 120, and 155 m included a pressure sensor. In addition, two Microcats SBE-37 were installed below the buoy at 1.5 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., 2006; Whelan et al., 2007, 2008, 2010; Santiago-Mandujano et al., 2009). Calibration of the mooring’s underwater instruments as well as data quality control and inter-comparisons with cruise observations are described in detail in Nosse et al. (2012) and Santiago-Mandujano et al. (2007). Briefly, 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. All these instruments are dunked in a cold freshwater bath before deployment and after recovery to generate a spike in the data to be used for synchronization of their internal clocks. 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-8 mooring returned full records of high quality data. Details on the meteorological measurements are available at http://uop.whoi.edu/projects/WHOTS/whotsdetails.html.
Figure 2.31: WHOTS-8 mooring diagram
In addition to the mooring data, CTD casts were conducted during the 12-20 June 2012 WHOTS-9 mooring recovery cruise measuring pressure, temperature, conductivity and dissolved oxygen. Ten CTD casts were conducted from June 13-16 at station 52 (near the WHOTS-8 buoy), station 50 (near the WHOTS-9 buoy) and at a test station (Station 1). Four CTD casts were conducted to obtain profiles for comparison with subsurface instruments on the WHOTS-8 mooring before recovery, and five casts were conducted for comparison with the WHOTS-9 mooring after deployment. These were sited approximately 500 m from the buoys. The comparison casts consisted of 4 yo-yo cycles between 10 dbar and 200 dbar and then nominally to 500 dbar (5th yo-yo cycle of each cast). Station numbers were assigned following the convention used during HOT cruises (see Table 2.25). The test cast at Station 1 was to 1024 dbar. 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-243 cruise conducted five days later (25-29 June, 2012), and the oxygen data were processed using the same oxygen calibration parameters.

Table 2.25: CTD stations occupied during the WHOTS-9 cruise

<table>
<thead>
<tr>
<th>Station/cast</th>
<th>Date</th>
<th>Time (UTC)</th>
<th>Location</th>
<th>Maximum pressure (dbar)</th>
</tr>
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<td>6/13/12</td>
<td>06:03</td>
<td>21° 28.06´ N, 158° 21.13´ W</td>
<td>1024</td>
</tr>
<tr>
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<td>6/14/12</td>
<td>15:49</td>
<td>22° 47.78´ N, 157° 54.04´ W</td>
<td>502</td>
</tr>
<tr>
<td>50 / 2</td>
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<td>19:47</td>
<td>22° 47.66´ N, 157° 53.81´ W</td>
<td>502</td>
</tr>
<tr>
<td>50 / 3</td>
<td>6/14/12</td>
<td>23:52</td>
<td>22° 47.86´ N, 157° 53.72´ W</td>
<td>502</td>
</tr>
<tr>
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<td>22° 47.80´ N, 157° 53.66´ W</td>
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<tr>
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</tr>
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<td>502</td>
</tr>
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</tbody>
</table>
3.0 CRUISE SUMMARIES

The cruise summaries presented here give an overview of the activities conducted during the 2012 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-239

Chief Scientist: S. CURLESS
R/V Ka’imikai-O-Kanaloa
17 - 21 January, 2012

Operations at Station ALOHA were conducted as planned throughout the cruise with only minor delays experienced. One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, thirteen 1000 m CTD casts, and one 250 m CTD cast were conducted at Station ALOHA. One 200 m yo-yo CTD cast was completed near the WHOTS mooring (Station 52) with five cycles completed. One near bottom cast was conducted at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. During the third day of the cruise both the Sediment Traps and the Gas Array traveled in a clockwise hook shaped pattern (to the NE and then wrapping around to the SW) from their respective deployment sites. The Primary Production Array drifted to the NW of its deployment site.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The Hyperpro was deployed and recovered successfully three times near noon. The optical package ACS/AC9/FRRf/LISST was deployed two times during the cruise, once around noon and once in the early morning. Due to a malfunction with the DH4, data from the two deployments was compromised. The ATE was successfully deployed, but due to communication errors with the instrument a trace metal free sample was not collected.

The thermosalinograph and the ship’s anemometers ran without interruption during the cruise. The fluorometer was running throughout the cruise but was leaking from the sample cell and provided questionable measurements. The ship’s ADCP system and the Knudsen sub-bottom profiler were not operational during the cruise. The Seabeam Multi-beam system was attempted to be used to provide a bottom reading but the computer could not talk to the Seabeam controller and was therefore not operational.

Winds during the first two days of the cruise were from the South at 15-20 kts and then become light and variable during the third day. The fourth day of the cruise was dominated by East winds at 10-15 kts. The swell was 4-6 ft during the first two days, lowering to 2-3 ft on the third day and coming back up to 4ft on the fourth day of the cruise.

We arrived at Snug Harbor for off-loading on January 21st, at 0745 (HST).
3.2 HOT-240

Chief Scientist: C. NOSSE
R/V Kilo Moana
23 - 27 March, 2012

Operations at Station Kahe were conducted as planned. A 500 m weight-test cast, 1000 m CTD cast and a Hyperpro cast were all completed.

The weather conditions during the transit to Station ALOHA were poor and remained poor once arriving on station. Sustained winds in excess of 35 knots were observed during the transit. On station, initial conditions were 12’ seas with winds ranging from 25-30 knots. The weather forecast indicated continued poor weather for March 24th with no predicted relief until the morning of March 26th.

After assessing the weather conditions, the sediment trap array was deployed. The Primary Productivity array could not be deployed as water could not be collected for the array when needed on March 25th. The Gas Array was also not deployed due to poor weather conditions.

One near-bottom CTD cast, nine 1000 m CTD casts and one 200 m CTD were conducted at Station ALOHA. One 200 m yo-yo CTD cast (with three cycles) was completed near the WHOTS mooring (Station 52). One near bottom cast was conducted at Station Kaena.

Five net tows for the HOT zooplankton collection were completed successfully; two during the day and three during the night. A third day net tow was called off in order to expedite CTD casts. The Hyperpro was deployed and recovered successfully two times near noon. The Hyperpro cast that regularly accompanies the Primary Productivity Array was not conducted. The optical package ACS/AC9/FRRf/LISST was deployed two times during the cruise, once in the early morning and once around noon. The early morning deployment did not return a full dataset.

The APEX drifter from the University of Washington was successfully deployed. The fluorometer, thermsosalinograph and the ship’s meteorological suite ran without interruption during the cruise. The underway $pCO_2$ system would not operate and requires additional parts for repair.

Winds were from the east throughout the cruise; in the 25-35 knot range during the first three days of the cruise, dropping under 20 knots for the remainder of the cruise. Swell was about 12-13 feet for the first three days of the cruise until dropping to about 5-6 feet.

We arrived at Snug Harbor for off-loading on March 27th at 0900 (HST). We were delayed for about an hour outside Honolulu Harbor due to a high volume of ship traffic.
Operations at Station Kahe were conducted as planned. A 500 m weight-test cast, 1000 m CTD cast and a Hyperpro cast were all completed.

Operations at Station ALOHA were conducted as planned until approximately 1200 (HST) on May 2. An accident requiring medical transport of a science party participant suspended operations for about 18 hours. Full details of the accident were given to the University of Hawaii Marine Center as well as the National Science Foundation. After providing medical transport for the injured party, there were approximately 10 hours available to complete our scientific objectives. The Gas and Sediment Trap Arrays were recovered and the remaining time was spent at Station ALOHA conducting CTD casts to provide profiles and collect samples for core and ancillary experiments. Given the limited time, the four remaining CTD casts were optimized by consolidating samples when possible and by limiting the target depth for two of the four casts (two 1000 m casts were replaced with a 200 m and 500 m cast).

One near-bottom CTD cast, eleven 1000 m CTD casts, one 500 m CTD cast and two 200 m CTD casts were conducted at Station ALOHA. One of the 200 m CTD casts was a yo-yo cast (with four cycles) near the WHOTS mooring (in effect, Station 52).

Four net tows for the HOT zooplankton collection were completed successfully; two during the day and two during the night. The Hyperpro was deployed and recovered successfully two times near noon. The Hyperpro cast at Station ALOHA could not descend to the target depth (despite two attempts) due to sea conditions and ship movement. The optical package ACS/AC9/FRRf/LISST was deployed two times during the cruise, once in the early morning and once around noon. Due to a suspected battery power issue, the ACS did not collect data during the early morning cast.

The fluorometer, thermosalinograph and the ship’s anemometer had one slight interruption during the cruise (outbound from Honolulu Harbor) when a UPS had to be changed out for some ship systems.

Winds were from the east throughout the cruise, in the 20-25 knot range. Swell ranged from 6 to 8 feet.

We arrived at Snug for off-loading on May 4th at 0740 (HST).
3.4 HOT-242

Chief Scientist: S. CURLESS
R/V Ka’imikai-O-Kanaloa
29 May - 2 June 2012

Operations at Station ALOHA were conducted as planned throughout the cruise with only minor delays experienced. To create more time in the schedule to recover Sea Glider 148 on June 1st, the 200 m yo-yo CTD cast at Station 52 was conducted before the recovery of the free drifting arrays.

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 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 was deployed and recovered successfully two times near noon. The third Hyperpro deployment originally scheduled for near noon on June 1st was cancelled to allow for the Sea Glider recovery. The optical package ACS/AC9/FRfR/LISST was deployed two times during the cruise, once around noon and once in the early morning. The ATE was successfully deployed three times, but due to communication errors with the instrument only two trace metal free samples were collected.

The thermosalinograph, fluorometer, and the ship’s anemometers ran without interruption during the cruise. The ship’s ADCP system and the Knudsen sub-bottom profiler were not operational during the cruise. A leak in the plumbing for the scientific sea water supply (forward of the thermosalinograph) created low water pressure for the entire science sea water system. OTG decreased the flow rate of sea water through the thermosalinograph to minimize the impact of low water pressure in the system, but this was not enough to allow for consistent temperature in the circulating on deck incubators. An extra supply line from the ship’s sea water system was added to the incubators to increase the water circulation and maintain a constant temperature for incubating samples.

Winds during the first two days of the cruise were from the ENE sustained at ~20kts. On the afternoon of the third and throughout the last day of the cruise the winds increased to ~25kts. Seas were 4-6ft with ~6-8ft swell throughout the cruise.

We arrived at Snug Harbor for off-loading on June 2nd, at 0751 (HST).
Operations at Station ALOHA were delayed during the first day of the cruise due to complicated weather conditions. The presence of a strong eastward current (~1 kt) combined with high (20-25 kt) easterly winds made keeping the ship on station with appropriate wire angles on array deployments and CTD casts quite difficult. To compensate for the time delays experienced, one 1000 m CTD cast in the 36 hour period was cancelled and therefore the burst period was shortened to only 33 hours. Water needs from the cancelled cast were re-assigned to other casts. Another slight delay was experienced on the second night at Station ALOHA when a side rail on the Caley Crane energy chain came off during the recovery of the CTD. KM engineers made repairs to the energy chain and the repairs were tested by exercising the crane before another CTD cast was deployed. Movement of the energy chain during CTD operations was then restricted for the remainder of the cruise.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts and twelve 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 four 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. All arrays drifted to the east of the center of Station ALOHA.

Seaglider #148 was successfully deployed at Station ALOHA on June 25th.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The Hyperpro was deployed and recovered successfully three times near noon. The optical package ACS/AC9/FRRf/LISST was deployed two times during the cruise, once around noon and once in the early morning. The ACS was out for servicing and was not deployed on this cruise. Two LISST’s were deployed on the optics cage to test the pressure sensors on both instruments.

The ATE was lost during its first deployment due to station keeping failure. The line securing the ATE to the ship was severed by either the ship’s rudder or screw.

The fluorometer, thermosalinograph and the ship’s meteorological suite ran without interruption during the cruise. The underway pCO2 system would not operate and requires additional parts for repair. The Caley Crane control and read out monitor in Lab #1 was not working.

Winds were from the east throughout the cruise at 20-25 kts for the first two days of the cruise and 15-20 kts for remainder of the cruise. A strong eastward current was present at Station ALOHA throughout the cruise. Seas were 8-10 ft for the first day of the cruise, and diminished to 6-8 ft for the rest of the cruise.
Operations at Station ALOHA were conducted as planned. A bending in the CTD wire caused by operator error during stowing of the Caley crane after the first cast at Station ALOHA, caused a slight delay in the deployment of the primary productivity cast (S2C2) as the wire had to be re-terminated. The cable was rapidly re-terminated by J. Snyder, which prevented a major change in the schedule, as this happened at a critical time right before the primary productivity water collection and subsequent time-dependent array deployment.

In an attempt to prevent twisting of the CTD wire, caused possibly by rosette spinning by the ship’s wake while the CTD is sitting at 5 m for bottle firing, bottles that are usually collected at 5 dbar were collected at 10 dbar for all casts, except for the casts sampling water for the primary productivity and gas arrays (S2C2 and S2C9). This did not seem to solve the wire twisting problem, as twists had to be removed from the wire almost after every cast. One of the science group members received a slight arm injury when the cover of one of the incubators was left unattended and fell on their arm. The person received medical attention by the First mate, and an incident report was filled.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, thirteen 1000 m CTD casts, and one 300 m 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. One near bottom cast was completed at Station Kaena.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. All arrays drifted to the northwest of the center of Station ALOHA.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The Hyperpro was deployed and recovered successfully three times near noon. The optical package ACS/AC9/FRRf/LISST was deployed four times on August 2nd, twice back to back deployments around noon and twice back to back deployments in the early morning. The ATE was deployed at Station ALOHA on July 31st and August 1st and 2nd, but only two trace metal samples were successfully collected.

The fluorometer, thermostalinograph and the ship’s meteorological suite ran without interruption during the cruise; however the data were not available in the ship’s intranet system because one of the computers (kmsnap) was not working. The underway $pCO_2$ system would not operate and requires additional parts for repair. The Caley Crane control and read out monitor in Lab #1 was not working.

Winds were from the eastnortheast throughout the cruise at 15-20 kts. A strong northwestward current was present at Station ALOHA throughout the cruise. Seas were 4-6 ft during the cruise.
3.7 HOT-245

Chief Scientist: S. CURLESS
R/V Kilo Moana
16 - 20 August 2012

Operations at Station ALOHA were conducted as planned. Small delays in the schedule occurred due to slowing of winch speed on casts to adjust the level wind on the Caley winch drum and due to the long transit back to Station ALOHA after recovering the Gas Array and Sediment Trap Array. Two separate issues with the operation of the Caley crane occurred on the cruise but did not affect the overall operational plan of the cruise.

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. All arrays drifted to west of the center of Station ALOHA.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. The Hyperpro was deployed and recovered successfully three times near noon. The optical package ACS/AC9/FRRf/LISST was deployed two times during the cruise, once around noon and once in the early morning. The ATE was deployed and recovered successfully three times on the cruise. Three trace metal samples were collected.

The fluorometer, thermosalinograph and the ship’s meteorological suite ran without interruption during the cruise, but the data were not available on the ship’s intranet system because one of the computers (kmsnap) was not working. The underway $p$CO$_2$ system would not operate and requires additional parts for repair. The Caley Crane control and read out monitor in Lab #1 was not working.

Winds were from the east throughout the cruise at ~15kts. Seas were 1-2 ft with a 3-5 ft easterly swell. The prevailing currents were to the west of the center of Station ALOHA.
Operations at Station ALOHA were conducted as planned.

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 Caley emergency stop was accidentally activated during two CTD recoveries, apparently caused by rough handling of the belly-pack controls.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully inside the ALOHA circle. All arrays drifted to the west/northwest of the center of Station ALOHA.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. Hyperpro casts (3 cycles each) were conducted on September 13th, 14th, and 16th. The optical package ACS/AC9/FRRf/LISST was deployed four times on September 16th, two back to back deployments in the early morning, and two at around noon. The ATE was deployed at Station ALOHA on September 14th, 15th, and 16th, however only two samples were obtained.

Communications with the HPM and data downloading were successfully conducted on September 15th.

The fluorometer, thermostalinograph, $pCO_2$ system, and the ship’s meteorological suite ran without interruption during the cruise. The Caley Crane control and read out monitor in Lab #1 was not working.

Winds were from the east throughout the cruise at 10-18 kts with smooth seas. A westward current was present at Station ALOHA throughout the cruise.
Operations at Station ALOHA were conducted as planned according to a modified cruise schedule due to a medical emergency on board. A member of the ship’s crew was evacuated at Waianae small boat harbor shortly after operations at Station Kahe were complete. Arrival at Station ALOHA was delayed by approximately 2 hours, therefore delaying the deployment of the Sediment Traps. The first CTD cast at Station ALOHA (S2C1) was shortened to 200 m in order to stay on schedule. Both of the near bottom CTD casts at Station ALOHA resulted in kinked .322” wire near the CTD rosette and had to be re-terminated. A problem with the level wind on the Caley winch developed during the upcast of the near bottom CTD cast at Station Kaena. Heave compensation was disengaged for the remainder of the upcast and the problem was subsequently corrected by changing out a worn roller on the level wind.

One 1000 m CTD cast was completed at Station Kahe. Two near bottom CTD casts, twelve 1000 m CTD casts and two 200 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. All arrays drifted to the WNW of their respective deployment locations.

The Apex float was recovered successfully.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. One handheld plankton net tow was completed on October 7th.

Hyperpro casts (3 cycles each) were conducted on October 6th, 7th, and 9th. The optical package ACS/AC9/FRRf/LISST was deployed four times on October 9th, two back to back deployments in the early morning, and two starting at 1000. The ATE was successfully deployed at Station ALOHA on October 8th.

Communications with the HPM and data downloading were successfully conducted on October 8th.

The fluorometer, thermosalinograph, $p$CO$_2$ system, and the ship’s meteorological suite ran without interruption during the cruise. However, the external thermosalinograph temperature showed suspicious variability indicating problems with the flow in the system. Also, the Caley crane control and read out monitor in Lab #1 was not working.

Winds were from the Southwest throughout the cruise at 5-10 kts and then increased to 15-20 kts starting on the evening of October 7th with smooth seas. There was a Northwesterly swell of 6-10 ft on October 9th. A westward current was present at Station ALOHA throughout the cruise.
Operations at Station ALOHA were conducted as planned, except that one of the Repeta pump samplings scheduled for December 3rd had to be cancelled due to time constraints.

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 trawl winch with the 0.681 wire and the A-frame were used for CTD operations because the Caley system was not operational.

The Sediment Traps, Primary Production Array, and Gas Array were all deployed and recovered successfully. The Primary Production array drifted 0.8 nm northwestward, and the other two arrays drifted southwestward to near the edge of Station ALOHA circle.

Six net tows for the core HOT zooplankton collection were completed successfully; three during the day, and three during the night. Hyperpro casts (3 cycles each) were conducted on December 2nd, 3rd, and 5th. The optical package ACS/AC9/FRRf/LISST was deployed four times on December 5th, two back to back deployments in the early morning, and two at around noon. The ATE was deployed at Station ALOHA on December 3rd.

Sampling with the deck-board diaphragm pump was conducted on December 4th and 5th. Communications with the HPM and data downloading were successfully conducted on December 4th.

The fluorometer, thermosalinograph, $p$CO$_2$ system, and the ship’s meteorological suite ran without interruption during the cruise. The broad band/narrow band Ocean Surveyor ADCP was working correctly during the cruise, but the Workhorse ADCP was out of service.

Winds were from the south throughout the cruise at 10-20 kts with a 5-8 ft swell. A thunderstorm hit us for about 2 hours late night on December 4th with heavy rain, lightning, and wind gusts up to 35 kt.
**4.0 RESULTS**

**4.1 Hydrography**

**4.1.1 2012 CTD Profiling Data**

Profiles of temperature, salinity, oxygen and potential density ($\sigma_0$) were obtained from data collected at Stations Kahe, ALOHA, and Kaena. The downcast CTD profiles from Station ALOHA during 2012 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 ($\sigma_0$). However, there is substantial cruise-to-cruise variability in both the position and magnitude of the chlorophyll maximum.

Profiles of the data collected for Stations Kahe and Kaena during 2012 are presented in Figures 6.1.4. Station Kaena was not visited during HOT-241 and 242, because of time constraints.

The potential temperature, salinity and oxygen profiles obtained from the deep casts at Station ALOHA during 2012 are presented in Figures 6.1.5-7.

**4.1.2 Time-series Hydrography, 1988-2012**

The hydrographic data collected during the first twenty four years of HOT are presented in a series of contour plots (Figures 6.1.8-23). These figures show the data collected in 2012 within the context of the longer time-series. The CTD data used in these plots are obtained by averaging the data collected during the 36-hour period of burst sampling. Therefore, much of the variability, which would otherwise be introduced by internal tides, has been removed. Figures 6.1.8 and 6.1.9 show the contoured time-series for potential temperature and density ($\sigma_0$) in the upper 1000 dbar for all HOT cruises through 2012. 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 6.1.9). 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 6.1.10-13 show the contoured time-series record for salinity in the upper 1000 dbar for all HOT cruises through 2012. The plots show both the CTD and bottle results plotted against pressure and potential density. Most of the differences between the contoured sections of bottle salinity and CTD salinity are due to the coarse distribution of bottle data in the vertical as compared to the CTD observations. Some of the bottles in Figure 6.1.13 are plotted at density values lower than the indicated sea surface density. This is due to surface density changing from cast to cast within each cruise, and even between the downcast and the upcast during a single cast.

Surface salinity is variable from cruise-to-cruise, with no obvious seasonal cycle and some substantial interannual variability. Relatively low surface salinities occurred during 1989, the early part of 1995, during 1996, and during the second part of 2004. A relative increase in surface salinity that started in the late months of 1997 continued throughout 2003, intensifying in the first half of 1999 and remaining with high values during the major part of 2000, 2001 and early 2002, showing a decrease in mid-2002, mid-2003, during the second half of 2004, in early 2005, during 2007, and mid-2008; and increasing again by the end of 2002, early 2003, late 2003, early 2004, early 2009, early to mid 2010, and early and late 2011 and 2012. This increase is also present in deeper layers reaching 200 dbar (Figure 6.1.10).

The salinity maximum is generally found between 50 and 150 dbar, and within the range 24-25 \( \sigma_0 \). 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 and 2012, 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 2012. 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 afterward.

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, and in the summer of 2011 and 2012. 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 during HOT-241 (see Figures. 6.1.1.c, 6.1.6, and 6.1.7), however its anomalous values were not as extreme as during HOT-122.

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

The oxygen minimum exhibits some interannual variability, with values less than 30 $\mu$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 6.1.24). 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 increasing trend started in late 2005 to reach record high values in mid-2010 to sharply decrease throughout 2012.

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 6.1.8).

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

During 1996, the intermediate waters between 27.0-27.8 \( \sigma_\theta \) recovered from anomalously low [nitrate + nitrite] which was observed during 1995 (Figure 6.1.18). This anomaly is apparent in a time-series of mean [nitrate + nitrite] between 27.0-27.8 \( \sigma_\theta \) (Figure 6.1.24). A decrease in [nitrate + nitrite] began in late 1994, with a comparable increase from mid-1995 through early 1996. The maximum decrease appears to be about 1 \( \mu \text{mol kg}^{-1} \) below 27.5 \( \sigma_\theta \) where nitrate concentrations are about 40 \( \mu \text{mol kg}^{-1} \). 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 \( \mu \text{mol kg}^{-1} \) for samples with a concentration of 40 \( \mu \text{mol kg}^{-1} \). Hence, the 1 \( \mu \text{mol kg}^{-1} \) 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 6.1.24).

Intermediate water SRP (between 27.0-27.8 \( \sigma_\theta \)) reached low values in early 1997, after a decreasing trend established in early 1994 (Figure 6.1.19). A time-series of mean SRP in this layer shows this trend clearly (Figure 6.1.24). The SRP maintained relatively low values throughout early 2001, when it increased sharply and maintained an increasing trend until 2005, to then start a decreasing trend ending in 2010 to values similar to those observed during 1997-2001. 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 \( \sigma_\theta \) vary during the decrease of phosphate from early 1994 through 1997 (Figure 6.1.24) without any apparent correlation.

4.2 Thermosalinograph

Thermosalinograph measurements of near-surface temperature (NST) and near-surface salinity (NSS), as well as navigation for the 2012 HOT cruises are presented in Figures 6.2.1a to j and Figures 6.2.2a to j. 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 2.2.2.2), the external temperature data from all cruises on board the R/V Kilo Moana were flagged as uncalibrated due to adverse warming as a result of water passing the pump before the remote temperature sensor. Problems with the thermosalinograph system during cruises were indicated in Section 2.2.2.2. For cruises HOT-246 and HOT-247 the corrected internal sensor temperatures are reported due to problems with the external sensor pump (Section 2.2.2.2, 2.2.2.4).
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 j.

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

The 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 j.

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). Cruises HOT-239, -241 and -242 conducted on the R/V Ka'imikai-O-Kanaloa are not included because the ADCP was inoperable. As explained earlier (Section 2.4), gaps in some of the northward transit plots were caused by rough weather, and gaps in some of the on-station data are due to excursions to retrieve the primary productivity array and floating sediment traps. 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 1988-2012 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 1988-2012 are presented in [Figure 6.5.2](#). A contour plot of dissolved inorganic carbon is shown in [Figure 6.5.3](#) and a contour plot of total alkalinity is shown in [Figure 6.5.4](#).

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

### 4.5.3 pH

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

### 4.5.4 Inorganic Nutrients

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

The chemiluminescent method of Cox (1980) as modified for seawater by Garside (1982) was used to determine the [nitrate+nitrite] content of near surface (0-200 m interval) water samples. [Figure 6.5.5](#) shows the profiles obtained from our low level [nitrate + nitrite] analyses at Station ALOHA during 2012. The upper 100 m is generally depleted in [nitrate + nitrite] (LLN) with values usually not exceeding 6 nmol kg\(^{-1}\). A contour plot of LLN from 0-100 dbar during the 1989-2012 time period is shown in [Figure 6.5.6](#).

Dissolved inorganic P (DIP) was analyzed using the MAGnesium Induced Coprecipitation (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 2012. 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 1989-2012 is shown in [Figure 6.5.8](#). Several trends are evident, including a general reduction in DIP concentrations from >90 nmol kg\(^{-1}\) in 1989-1990 to <30 nmol kg\(^{-1}\) in 2001. The 0-100 m DIP depth integrated inventory was reduced from a high of >10 mmol P m\(^{-2}\) to a low of <2.5 mmol P m\(^{-2}\); more recently, DIP inventories appear to have stabilized and increased.

4.5.5 Total Organic Carbon

A contour plot of total organic carbon (TOC) from 0 to 1000 dbar over the 2002-2010 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 24 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 16 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 1988-2012 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 1988-2012 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 α/β-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 α/β-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 2012 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 24 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 24 year data set is $516 \pm 133$ mg C m$^{-2}$ d$^{-1}$. Although this value is higher than historical measurements for the oceanic central gyres (Ryther 1969), it is consistent with more recent measurements (Martin et al., 1987; Laws et al., 1989; Knauer et al., 1990).

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

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<th>Pigments (mg m$^{-2}$)</th>
<th>Incubation Duration (hrs)</th>
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* Calculated using our LiCOR logger which was probably underestimating values.
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 1988-2012 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 vary 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.

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<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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4.7 Optical Measurements

4.7.1 Downwelling Irradiance and Upwelling Radiance

Photosynthetically available radiation (PAR) was measured using a Satlantic HyperPro. Figure 6.7.1 shows the time-series of the 1 % light level and K$_{\text{PAR}}$ during the 15 years we’ve been collecting in-situ PAR data. Both vary seasonally. The average 1 % light-level at Station ALOHA is 106.4 m while the average K$_{\text{PAR}}$ between 100 & 150m is 0.0437 m$^{-1}$. Downwelling irradiance measured during the Primary Production incubation period is shown in Table 4.1.

4.7.2 Fast Repetition Rate Fluorometry (FRRF)

In order to determine photosynthetic properties controlling variability in primary production, in situ, time-series measurements of Fast Repetition Rate Fluorometry (FRRF) have been conducted. Photosynthetic efficiency, as indicated by F$_V$/F$_M$ (Figure 6.7.2a-g, left panel), was high and constant through the water column (averaging 0.60 ± 0.10), exceeding the theoretical maximum (i.e. > 0.65) below the Deep Chlorophyll Maximum Layer (DCML) (0.75 ± 0.10) and in some discrete layers between 40 and 70m. Averaged F$_V$/F$_M$ through the mixed
layer were linearly related to mixed layer depth (MLD), suggesting the influence on photosynthetic activity by possible nutrient injections or mixing-dependent light adaptation.

The FRRF-derived initial slope of the P vs. E curve (α) (Figure 6.7.2a-g, center panel) was approximately six times lower at the surface than at the DCML, highlighting the presence of high-and low-light adapted populations. The derived ΦC (quantum yield of photosynthesis) was low (0.0016 mol C mol quanta⁻¹) throughout the year, with maxima in the DCML region. ΦC was significantly related to changes in functionally reaction centers (linear) and in α (exponential), and to a lesser extent to Fv/FM (linear). Significant (Δ = ± 100%) daily variations in primary productivity (Figure 6.7.2a-g, right panel), driven by changes in α, were also found in a couple cruises.

These results show a high photosynthetic efficiency in this oligotrophic region, highlighting that photoautotrophs may have successfully optimized their photosynthetic apparatus to the low nutrient environment. The absorption of light (α), and not the efficiency of light utilization (Fv/FM), appears to be the physiological parameter driving ΦC variations, daily productivity and to some extent the observed aperiodic variation in the NPSG. (Corno et al. 2006)

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 range from 3 to 7 x 10⁵ 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 are found at concentrations ranging from around 2 to 3 x 10⁵ ml⁻¹ at the surface and usually decrease with depth but with a subsurface maximum between 75 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 range from 1 to $3 \times 10^3$ ml$^{-1}$, and decrease with depth with a subsurface maxima between 50 and 100 m. The abundances of picoeukaryotes typically ranges from 1 to $2 \times 10^3$ 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 1994-2012 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-8 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 - p), as well as contour plots of these variables as a function of time and depth (Figure 6.10.1.q).

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-9 mooring recovery cruise are shown in plots of temperature, conductivity, salinity and dissolved oxygen as a function of depth (Figures 6.10.4.a - e).

Data obtained with the WHOTS buoy meteorological instruments during HOT cruises conducted on the R/V Kilo Moana are shown together with the ship’s meteorological observations taken at 5 minute intervals (Figures 6.10.5.a-g). 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. Figures (4) for cruises after HOT-242 include the RM Young Ultrasonic and the port RM Young 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.

The Kilo Moana’s port anemometer had problems during HOT-247, yielding intermittent incorrect wind directions. The starboard anemometer and the Ultra sonic anemometer functioned properly, and the port anemometer was fixed before the next HOT-248 cruise.

The ship’s Eppley Precision Infrared Radiometer, which failed after cruise HOT-232 (see HOT-2011 Data Report), yielded incorrect long wave radiation values in all subsequent cruises until before HOT-247. During HOT-247 the instrument still showed offset in the data during two 1/2 day periods, but it worked correctly during the following HOT-248 cruise. Air temperatures measured with the Rotronic Instrument Corp. humidity probe yielded values about 1 °C higher than those measured by the RM Young Resistive Temperature Device and the buoy’s instruments during cruises HOT-243 through -248, and it exhibited glitches during cruises HOT-244 through -248, which in turn caused glitches in the humidity data.
5.0 REFERENCES


111


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/m$^3$ [2nd panel] at Station ALOHA. Chloropigment values have been offset by 0.2 μg/l for both plots.

Figure 6.1.4a-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 6.1.5: [Upper panel] Potential temperature versus pressure for all deep casts in 2012. [Lower panel]: Potential temperature versus pressure deeper than 2500 dbar for all deep casts in 2012.

Figure 6.1.6: [Upper panel] Salinity versus potential temperature for all deep casts in 2012. [Lower panel]: Salinity versus potential temperature for all deep casts in 2012 in the 1-5 °C range.

Figure 6.1.7: [Upper panel] Oxygen concentrations from calibrated oxygen sensor data versus potential temperature for all deep casts in 2012. [Lower panel] Oxygen versus potential temperature for all deep casts in 2012 in the 1-5 °C range.

Figure 6.1.8: Contour plot of CTD potential temperature versus pressure for HOT cruises 1-248.

Figure 6.1.9: Contour plot of $\sigma_\theta$, calculated from CTD pressure, temperature and salinity, versus pressure for HOT cruises 1-248.

Figure 6.1.10: Contour plot of CTD salinity versus pressure for HOT cruises 1-248.
**Figure 6.1.11:** Contour plot of CTD salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.12:** Contour plot of bottle salinity versus pressure for HOT cruises 1-248. The solid circles indicate location of samples in the water column.

**Figure 6.1.13:** Contour plot of bottle salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.14:** Contour plot of bottle oxygen versus pressure for HOT cruises 1-248. The solid circles indicate location of samples in the water column.

**Figure 6.1.15:** Contour plot of bottle oxygen versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.16:** Contour plot of [nitrate + nitrite] versus pressure for HOT cruises 1-248. The solid circles indicate location of samples in the water column.

**Figure 6.1.17:** Contour plot of [nitrate + nitrite] versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.18:** Contour plot of [nitrate + nitrite] versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-248.

**Figure 6.1.19:** Contour plot of soluble reactive phosphorus versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-248.

**Figure 6.1.20:** Contour plot of soluble reactive phosphorus versus pressure for HOT cruises 1-248. The solid circles indicate location of samples in the water column.

**Figure 6.1.21:** Contour plot of soluble reactive phosphorus versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface

**Figure 6.1.22:** Contour plot of silicate versus pressure for HOT cruises 1-248. The solid circles indicate location of samples in the water column.

**Figure 6.1.23:** Contour plot of silicate versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-248. A heavy line connects the average $\sigma_0$ at the sea surface.

**Figure 6.1.24:** Time series of mean bottle dissolved oxygen for HOT cruises 1-248 (upper panel), [nitrate + nitrite] (middle panel) and soluble reactive phosphorus (lower panel) between 27.0 and 27.8 $\sigma_0$ isopycnals. The smooth line is the spline fit to the data. The asterisks indicate the annual mean.
6.2 Thermosalinograph

Figure 6.2.1a-j: Thermosalinograph data for HOT-239 through -248 cruises in 2012. Continuous near-surface temperature, salinity and \( \sigma_0 \) (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. The temperatures from cruises HOT-240, and -243 through -248 were flagged uncalibrated due to uncertainty in the R/V Kilo Moana thermosalinograph temperatures (see text).

Figure 6.2.2a-j: Navigation data during HOT-239 through -248 cruises in 2012: 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 2012 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 2012 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 2012 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 2012 HOT cruises.

Figure 6.3.3: [Upper panel] Sea surface temperature minus dry air temperature while at Station ALOHA for 2012 HOT cruises (open circles), and WHOTS buoy hourly measurements throughout the year (continuous line). [Lower panel] Relative humidity at Station ALOHA for 2012 HOT cruises, and WHOTS buoy hourly measurements throughout the year (continuous line).

Figures 6.3.4a to j: [Upper panel] True winds measured at Station ALOHA for 2012 HOT cruises. [Middle panel] Continuous true wind record from the ship’s anemometer during HOT cruises. [Lower panel] True winds measured by WHOTS buoy. The orientation of the arrows indicates the wind direction; up is northward, right is eastward.

6.4 ADCP Measurements

Figures 6.4.1a-g: Velocity fields at Station ALOHA obtained with an RD Instruments Ocean Surveyor 38 in narrow band mode during 2012 cruises. Cruises HOT-239, -241, and -242 conducted on the R/V Ka'imikai-O-Kanaloa are not included because the ADCP was inoperable (see text). Top panel shows 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. The bottom panel shows 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-g: 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 during 2012 cruises. Cruises HOT-239, -241, and -242 are not included because the ADCP was inoperable. 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 1-248 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 1-248. [Lower panel] Mixed layer dissolved inorganic carbon (normalized to 35 ppt salinity) for HOT cruises 1-248. 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 1-248 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 1-248 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 2012 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 1-248. [Lower panel] 0-100 dbar integral of LLN at Station ALOHA for HOT cruises 1-248.

Figure 6.5.7: Depth profile from 0-250 dbar of low-level soluble reactive phosphorus at Station ALOHA for 2012 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 soluable reactive phosphorus at Station ALOHA for HOT cruises 1-248. [Lower panel] 0-100 dbar integral of LLP at Station ALOHA for HOT cruises 1-248.

**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 1-248 from 0-50 dbar. [Lower panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-248 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 1-248. Solid dots indicate water column sample locations.

**Figure 6.5.12:** [Upper panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-248 from 0-50 dbar. [Lower panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-248 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 1-248. Solid dots indicate water column sample locations.

**Figure 6.5.14:** [Upper panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-248 from 0-50 dbar. [Lower panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-248 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 1-248. Solid dots indicate water column sample locations.

**Figure 6.5.16:** [Upper panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-248 from 0-50 dbar. [Lower panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-248 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 79-248. 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 2-248. Solid dots indicate water column sample locations.

**Figure 6.5.19:** Contour plots from 0-200 dbar of HPLC chlorophyll ($a$, $b$ & $c$) concentrations at Station ALOHA for HOT cruises 1-248.

**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 1-248.
Figure 6.5.21: Contour plots from 0-200 dbar of HPLC photo-protective carotenoid (diadinoxanthin, zeaxanthin & α- plus β-carotene) concentrations at Station ALOHA for HOT cruises 1-248.

Figure 6.5.22: Contour plot from 0-350 dbar of particulate adenosine 5′-triphosphate concentrations at Station ALOHA for HOT cruises 1-248. 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 1988-2012. Filled circles and crosses indicate in situ and on deck incubations, respectively. Solid line represents the average production (516 mg C m⁻² d⁻¹), dashed lines are ± one standard deviation (133 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 1-248. Solid dots indicate water column sample locations.

Figure 6.6.3: Particulate carbon flux [Top panel] , Particulate nitrogen flux [2nd panel], Particulate phosphorus flux [3rd panel] and Particulate silica flux [Bottom panel] at 150 m measured on all HOT cruises from 1988-2012. Error bars represent the standard deviation of determinations from triplicate particle interceptor traps.

6.7 Optical Measurements

Figure 6.7.1: [Upper panel] Depth of the 1% surface PAR light level for HOT cruises 90-248. The solid red line represents the average 1% surface PAR light depth (106.4 m) at Station ALOHA. [Lower panel] Mean PAR attenuation coefficient (Kₚₚₐᵣ) for HOT cruises 90-248 from 100-150m. The solid red line represents the average Kₚₚₐᵣ (0.0437 m⁻¹) at Station ALOHA.

Figure 6.7.2a-g: [Left panel] Vertical profile of photosynthetic efficiency from 0-200 m [Center panel] Profile of FRRF-derived initial slope of the P vs. E curve [Right panel] Vertical profile of in situ primary productivity rates derived by Fast Repitition Rate Fluorometry (FRRF)

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 2012.

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 177-248. 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 2012.

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 23-248. 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 51-248. 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 SN 1835 deployed at 1.5 m on the WHOTS-8 mooring.

Figure 6.10.1.b: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6893 deployed at 15 m on the WHOTS-8 mooring.

Figure 6.10.1.c: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6894 deployed at 25 m on the WHOTS-8 mooring.

Figure 6.10.1.d: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6895 deployed at 35 m on the WHOTS-8 mooring.

Figure 6.10.1.e: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6896 deployed at 40 m on the WHOTS-8 mooring.

Figure 6.10.1.f: Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6887 deployed at 45 m on the WHOTS-8 mooring.

Figure 6.10.1.g: Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6897 deployed at 50 m on the WHOTS-8 mooring.
**Figure 6.10.1.h:** Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6898 deployed at 55 m on the WHOTS-8 mooring.

**Figure 6.10.1.i:** Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6899 deployed at 65 m on the WHOTS-8 mooring.

**Figure 6.10.1.j:** Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 3618 deployed at 75 m on the WHOTS-8 mooring.

**Figure 6.10.1.k:** Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6888 deployed at 85 m on the WHOTS-8 mooring.

**Figure 6.10.1.l:** Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 3617 deployed at 95 m on the WHOTS-8 mooring.

**Figure 6.10.1.m:** Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6889 deployed at 105 m on the WHOTS-8 mooring.

**Figure 6.10.1.n:** Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6890 deployed at 120 m on the WHOTS-8 mooring.

**Figure 6.10.1.o:** Temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 3634 deployed at 135 m on the WHOTS-8 mooring.

**Figure 6.10.1.p:** Pressure, temperature, salinity and potential density ($\sigma_0$) from Microcat SBE-37 SN 6891 deployed at 155 m on the WHOTS-8 mooring.

**Figure 6.10.1.q:** Temperature, salinity and potential density ($\sigma_0$) contours as a function of depth and time from Microcat instruments in the WHOTS-8 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-8 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-8 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-8 mooring.

**Figure 6.10.4.a:** Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-9 cruise, CTD Station 1 cast 1 and Station 50 cast1.

**Figure 6.10.4.b:** Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-9 cruise, CTD Station 50 casts 2 and 3.

**Figure 6.10.4.c:** Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-9 cruise, CTD Station 50 casts 4 and 5.
**Figure 6.10.4.d:** Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-9 cruise, CTD Station 52 casts 1 and 2.

**Figure 6.10.4.e:** Profiles of temperature, conductivity, salinity, and oxygen data during WHOTS-9 cruise, CTD Station 52 casts 3 and 4.

**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-240 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-240 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-240 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-243 cruise.

**Figure 6.10.5.b.2:** Same as in Figure 6.10.5.a.2, but for the HOT-243 cruise.

**Figure 6.10.5.b.3:** Same as in Figure 6.10.5.a.3, but for the HOT-243 cruise.

**Figure 6.10.5.b.4:** Time-series of wind speed [top panel] and direction [second panel] relative to the ship; “true” wind speed [third panel] and direction [fourth panel] in Earth coordinates for the Ultrasonic (blue) and the port RM Young (red) anemometers on the R/V *Kilo Moana* during the HOT-243 cruise.

**Figure 6.10.5.c.1:** Same as in Figure 6.10.5.a.1, but for the HOT-244 cruise.

**Figure 6.10.5.c.2:** Same as in Figure 6.10.5.a.2, but for the HOT-244 cruise.

**Figure 6.10.5.c.3:** Same as in Figure 6.10.5.a.3, but for the HOT-244 cruise.

**Figure 6.10.5.c.4:** Same as in Figure 6.10.5.b.4, but for the HOT-244 cruise.

**Figure 6.10.5.d.1:** Same as in Figure 6.10.5.a.1, but for the HOT-245 cruise.

**Figure 6.10.5.d.2:** Same as in Figure 6.10.5.a.2, but for the HOT-245 cruise.
Figure 6.10.5.d.3: Same as in Figure 6.10.5.a.3, but for the HOT-245 cruise.

Figure 6.10.5.d.4: Same as in Figure 6.10.5.b.4, but for the HOT-245 cruise.

Figure 6.10.5.e.1: Same as in Figure 6.10.5.a.1, but for the HOT-246 cruise.

Figure 6.10.5.e.2: Same as in Figure 6.10.5.a.2, but for the HOT-246 cruise.

Figure 6.10.5.e.3: Same as in Figure 6.10.5.a.3, but for the HOT-246 cruise.

Figure 6.10.5.e.4: Same as in Figure 6.10.5.b.4, but for the HOT-246 cruise.

Figure 6.10.5.f.1: Same as in Figure 6.10.5.a.1, but for the HOT-247 cruise.

Figure 6.10.5.f.2: Same as in Figure 6.10.5.a.2, but for the HOT-247 cruise.

Figure 6.10.5.f.3: Same as in Figure 6.10.5.a.3, but for the HOT-247 cruise.

Figure 6.10.5.f.4: Same as in Figure 6.10.5.b.4, but for the HOT-247 cruise.

Figure 6.10.5.g.1: Same as in Figure 6.10.5.a.1, but for the HOT-248 cruise.

Figure 6.10.5.g.2: Same as in Figure 6.10.5.a.2, but for the HOT-248 cruise.

Figure 6.10.5.g.3: Same as in Figure 6.10.5.a.3, but for the HOT-248 cruise.

Figure 6.10.5.g.4: Same as in Figure 6.10.5.b.4, but for the HOT-248 cruise.
7.0 HOT PROGRAM PRESENTATIONS AND PUBLICATIONS

The following is a listing of Presentations & Publications as of August 2014. 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.


7.2 Invited/Contributed Book Chapters and Refereed Publications


69. 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.


72. 1996 Firing, E. Currents observed north of Oahu during the first five years of HOT. Deep-Sea Research II 43, 281-303.


110. 1998 Li, W. K. W. Annual average abundance of heterotrophic bacteria and *Synechococcus* in surface ocean waters. Limnology and Oceanography 43(7),1746-1753.


International symposium on CO2 in the Oceans, CGER/NIES, Tsukuba, Japan, pp. 317-323.


130. 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.


274. 2004 Morris, R. M., M. S. Rappé, E. Urbach, S. A. Connan and S. J. Giovannoni. Prevalence of the *Chloroflexi*-related SAR202 bacterioplankton cluster throughout the
mesopelagic zone and deep ocean. Applied and Environmental Microbiology 70(5), 2836-2842.


397. 2008 Kanda, J. Vertical profiles of nitrate uptake obtained from in situ \textsuperscript{15}N incubation experiments in the western North Pacific. Journal of Marine Systems 71(1-2), 63-78.


165


457. 2009 Martiny, A. C., Y. Huang, W. Li. Occurrence of phosphate acquisition genes in Prochlorococcus cells from different ocean regions. Environmental Microbiology 11, 1340-1347.


527. 2011 Chang Y. L. and L. Y. Oey. Interannual and seasonal variations of Kuroshio transport east of Taiwan inferred from 29 years of tide-gauge data. Geophysical Research Letters 38(8), L08603.


7.3 Submitted Papers


2. Church, M. J., M. W. Lomas and F. Muller-Karger. Sea Change: Charting the course for biogeochemical ocean time series research in a new millennium. Submitted to Deep Sea Research II.


7.4 Thesis and Dissertations


7.5 Data Reports and Manuals


7.6 Newsletters


11. 1992 Firing, E. and P. Hacker. ADCP results from WHP P16/P17. WOCE Notes, 4(3), 6-
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**


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**

s) Nolla, H., J. Kirshtein, M. Landry, D. Karl, L. Campbell and D. Pence. **Flow Cytometry Correction Factors for Enumeration of Heterotrophic Bacteria and Phytoplankton**

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

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

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

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

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

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

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

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

4) **Ocean Carbon & Biogeochemistry - Sea Change: Charting the Course for Ecological and Biogeochemical Ocean Time Series Research, 21-23 September 2010, Honolulu, HI**
a) Welcome/Introduction/Workshop objectives (Matthew Church, UH)
b) The Bermuda Atlantic Time-series Study (Michael Lomas, BIOS)
c) The Hawaii Ocean Time-series (Matthew Church, UH)
d) The CARIACO Oceanographic Time-Series Program (Frank Muller-Karger, USF)
e) Plenary 1: Cross ecosystem perspectives on aquatic biogeochemistry and plankton community structure (Robert Sterner, University of Minnesota)
f) Ocean Biogeochemistry Research Opportunities Using the Ocean Observatories Initiative Infrastructure (Kendra Daly)
g) An update on the European network of marine observatories (Richard Lampitt)
h) The Ocean Time Series Advisory Committee (OTSAC): An introduction (Ken Johnson)
i) Evening plenary: "The Joy of ocean Time-Series" (David Karl, University of Hawaii)
j) Plenary 2: Biogeochemical and ecological coupling or decoupling of the epipelagic and deep sea: regional to global implications (Richard Lampitt, NOC, Southampton)
k) Plenary 3: Autonomous platform time series (Ken Johnson, MBARI)
l) Plenary 4: Ocean-time series as windows into scales of variability in the sea (Francisco Chavez, MBARI)
m) Concluding remarks (Matthew Church, UH)
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://mana.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 mana.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 also located on another 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. This web page is the springboard from which the homepages of the Physical Oceanography (PO) and Biogeochemistry & Ecology components are accessible. 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-hots-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)
  - Macrzooplankton (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
  - 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**
  • **Macrozooplankton** (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**
Station ALOHA HOT 239

Figure 6.1.1a
Figure 6.1.1b
Station ALOHA HOT 242

Figure 6.1.1d
Station ALOHA HOT 243

Figure 6.1.1e
Figure 6.1.1f
Figure 6.1.1h
Station ALOHA HOT 247

Figure 6.1.1i
Figure 6.1.1j
Figure 6.1.2b
Figure 6.1.2c
Figure 6.1.2d
Figure 6.1.2f
Figure 6.1.2g
Figure 6.1.2h
Figure 6.1.2i
Figure 6.1.2j
Figure 6.1.3a
Figure 6.1.3d
Figure 6.1.3e
Figure 6.1.3f
Figure 6.1.3h
Figure 6.1.3j
Figure 6.1.4b
Figure 6.1.4d
Kahe Pt. HOT 243

Kaena Pt.

Figure 6.1.4e
Kahe Pt. HOT 244

Kaena Pt.

Figure 6.1.4f
Figure 6.1.4g
Figure 6.1.4h
Figure 6.1.4i
Figure 6.1.5
Figure 6.1.6
HOT 1–248 Potential Temperature

Figure 6.1.8
HOT 1–248 Nitrate + Nitrite [umol/kg]

Figure 6.1.17
HOT 1–248 Soluble Reactive Phosphorus [μmol/kg]
Figure 6.1.22

HOT 1–248 Silicate [umol/kg]

Pressure (dbar)
HOT 1–248 Mean Oxygen between $\sigma_\theta$ 27.0 and 27.8

HOT 1–248 Mean [Nitrate+Nitrite] between $\sigma_\theta$ 27.0 and 27.8

HOT 1–248 Mean Soluble Reactive Phosphorus between $\sigma_\theta$ 27.0 and 27.8

Figure 6.1.24
HOT-239 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.1a
HOT-240 Thermosalinograph, \( o=\text{CTD at 8 dbar}, x=\text{salinity bottle} \)

Figure 6.2.1b
HOT-241 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.1c
HOT-242 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.1d
HOT-243 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

June 2012 (UTC)

Figure 6.2.1e
Figure 6.2.1f
HOT-246 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

September 2013 (UTC)

Figure 6.2.1h
HOT-247 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

October 2012 (UTC)

Figure 6.2.1i
HOT-248 Thermosalinograph, o=CTD at 8 dbar, x=salinity bottle

Figure 6.2.1j
Figure 6.2.2a
Figure 6.2.2b
HOT-241 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

April–May 2012 (UTC)

Figure 6.2.2c
Figure 6.2.2d
HOT-244 Navigation and Ship Speed

Figure 6.2.2f
Figure 6.2.2g
Figure 6.2.2h
HOT−247 Navigation and Ship Speed

Latitude (N)

Longitude (W)

Ship Speed (m/s)

October 2012 (UTC)

Figure 6.2.2i
HOT 239–248 Dry Bulb Air Temperature

Dry bulb air temperature (°C)

2012

Wet Bulb Air Temperature

Wet bulb air temperature (°C)

2012

Figure 6.3.2
HOT 239–248 SST – Dry Air Temperature

Relative Humidity

Figure 6.3.3
HOT 239 Shipboard True Winds, Observed

HOT 239−True Winds, from the continuous record of the ship

HOT 239 − True Winds, WHOTS buoy data

Figure 6.3.4a
HOT 240 Shipboard True Winds, Observed

HOT 240−True Winds, from the continuous record of the ship

HOT 240 – True Winds, WHOTS buoy data

Figure 6.3.4b
HOT 241 Shipboard True Winds, Observed

HOT 241−True Winds, from the continuous record of the ship

HOT 241 − True Winds, WHOTS buoy data

Figure 6.3.4c
HOT 242 Shipboard True Winds, Observed

HOT 242−True Winds, from the continuous record of the ship

HOT 242 – True Winds, WHOTS buoy data

Figure 6.3.4d
HOT 243 Shipboard True Winds, Observed

HOT 243 – True Winds, from the continuous record of the ship

HOT 243 – True Winds, WHOTS buoy data

Figure 6.3.4e
HOT 245 Shipboard True Winds, Observed

HOT 245–True Winds, from the continuous record of the ship

HOT 245 – True Winds, WHOTS buoy data

Figure 6.3.4g
HOT 246 Shipboard True Winds, Observed

HOT 246 − True Winds, from the continuous record of the ship

HOT 246 − True Winds, WHOTS buoy data

Figure 6.3.4h
HOT 247 Shipboard True Winds, Observed

HOT 247−True Winds, from the continuous record of the ship

HOT 247 – True Winds, WHOTS buoy data

Figure 6.3.4i
HOT 248 Shipboard True Winds, Observed

HOT 248–True Winds, from the continuous record of the ship

HOT 248 – True Winds, WHOTS buoy data

Figure 6.3.4j
Harmonic Analysis of Velocity

- Mean + trend
- Semidiurnal: 12.42 hours
- Diurnal: 24 hours

Figure 6.4.1a
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
Harmonic Analysis of Velocity

- Mean + trend
- Semidiurnal: 12.42 hours
- Diurnal: 24 hours
- Inertial: 31 hours

Figure 6.4.1g
Figure 6.4.2a
Figure 6.4.2b
Figure 6.4.2c
Figure 6.4.2d
Figure 6.4.2g
Figure 6.5.1

HOT 1-248 Bottle Dissolved Oxygen [\mu\text{mol kg}^{-1}]
HOT 1-248 Dissolved Inorganic Carbon [μmol kg⁻¹]

Figure 6.5.3
Figure 6.5.5
HOT 1-248 Low-Level NO$_2$+NO$_3$ [nmol kg$^{-1}$]

Figure 6.5.6
Figure 6.5.7
Figure 6.5.7 continued
HOT 1-248 Low-Level Phosphorus [nmol kg\(^{-1}\)]

Pressure [cibars]

Sampling Date

Figure 6.5.8
HOT 1–248 (0–50 dbar means)

Particulate Carbon [μmol kg⁻¹]

Sampling Date

HOT 1–248 (50–100 dbar means)

Particulate Carbon [μmol kg⁻¹]

Sampling Date

Figure 6.5.10
HOT 1–248 (0–50 dbar means)

HOT 1–248 (50–100 dbar means)

Figure 6.5.12
Figure 6.5.16

HOT 79–248 (0–50 dbar means)

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

Sampling Date

HOT 79–248 (50–100 dbar means)

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

Sampling Date
HOT 79-248 Particulate Biogenic Silica [nmol kg$^{-1}$]

Figure 6.5.17
HOT 2-248 Fluorometric Chlorophyll a [mg m\(^{-3}\)]
Figure 6.5.19
HOT 1-248 19'-Butanoyloxyfucoxanthin [µg m⁻³]

HOT 1-248 Fucoxanthin [µg m⁻³]

HOT 1-248 19'-Hexanoyloxyfucoxanthin [µg m⁻³]

Figure 6.5.20
Figure 6.5.21
Figure 6.6.1

Primary Production (mg C m$^{-2}$ d$^{-1}$)

Sampling Date

HOT 1–248

Primary Production (mg C m$^{-2}$ d$^{-1}$)

Sampling Date

HOT 1–248
HOT 90–248  1% Light Level

Depth [m]

HOT 90–248 (100–150 m means)

$K_{PAR} \text{ [m}^{-1}]$

Figure 6.7.1
Figure 6.7.2a
Figure 6.7.2b
Figure 6.7.2c
Figure 6.7.2d
Figure 6.7.2e

- **FV/FM**
- **HOT-149**
- **Alpha (g C mol photon^{-1} m^2 g Chl a^{-1})**
- **FRRF-PP (mg C m^{-3} hr^{-1})**
Figure 6.7.2g
Figure 6.8.1
Figure 6.8.1 continued
Figure 6.8.3 continued
WHOTS–8, 2 m. SN 1835

Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.a
Temperature ($^\circ$C) and Salinity ($\sigma_{\theta}$ (kg m$^{-3}$)) graphs showing data from different months (Oct11, Jan12, Apr12) for WHOTS–8, 15 m SN 6893.

Figure 6.10.1.b
Temperature (°C)

Salinity

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

Oct11  Jan12  Apr12

Figure 6.10.1.c
Temperature (°C)

Salinity

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

Figure 6.10.1.e
Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.g
WHOTS–8, 55 m. SN 6898

Temperature (°C)

Salinity

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

Figure 6.10.1.h
Temperature (°C)

Salinity

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

**Figure 6.10.1.i**
Temperature (°C) and Salinity (σθ (kg m⁻³)) over time from October 2011 to April 2012 for WHOTS-8, 75 m SN 3618.
Figure 6.10.1.k
WHOTS–8, 95 m. SN 3617

Temperature (°C)

Salinity

σθ (kg m⁻³)

Figure 6.10.1.l
WHOTS–8, 105 m. SN 6889

Pressure (dbar)

Temperature (°C)

Salinity

σθ (kg m⁻³)

Oct11  Jan12  Apr12

Figure 6.10.1.m
Temperature (°C)

Salinity

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

Figure 6.10.1.o
WHOTS-8, 155 m. SN 6891

- Pressure (dbar)
- Temperature (°C)
- Salinity
- $\sigma_\theta$ (kg m$^{-3}$)

**Figure 6.10.1.p**
Figure 6.10.1.q
Figure 6.10.2.a
WHOTS–8, ADCP, Zonal Current (m s\(^{-1}\))

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

Figure 6.10.2.b
WHOTS-9 Cruise CTD : Station 1 Cast 1

WHOTS-9 Cruise CTD Yo-Yo : Station 50 Cast 1

Figure 6.10.4.a
Figure 6.10.4.b
WHOTS-9 Cruise CTD Yo-Yo : Station 50 Cast 4

Temperature (°C)
Pressure (dbar)
Conductivity (S/m)
Salinity
Oxygen (μmol kg⁻¹)

WHOTS-9 Cruise CTD Yo-Yo : Station 50 Cast 5

Temperature (°C)
Pressure (dbar)
Conductivity (S/m)
Salinity
Oxygen (μmol kg⁻¹)

Figure 6.10.4.c
Figure 6.10.5.a.2
Figure 6.10.5.a.3
Figure 6.10.5.b.1
Figure 6.10.5.b.2
HOT-243 Red line = Kilo Moana, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

Pressure (mbar)

Rain Rate (mm/hr)

Rain accum (mm)

RM Young Precip (mm)

Figure 6.10.5.b.3
Figure 6.10.5.b.4
HOT-244 Red – Port anemometer, Blue – Starboard anemometer

Relative Wind Speed (m/s)

Relative Wind Direction (°)

Ship Speed (m/s)

True Wind Speed (m/s)

True Wind Direction (°)

Day (2012)

Figure 6.10.5.c.1
Figure 6.10.5.c.2
Figure 6.10.5.c.3
HOT-244 Relative Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT-244 Relative Wind Direction. Blue = ULTRA, Red = RM Young (Port)

HOT-244 True Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT-244 True Wind Direction. Blue = ULTRA, Red = RM Young (Port)

Figure 6.10.5.c.4
HOT-245 Red line = Kilo Moana, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

Red line = RM Young RTD, Blue line = Humidity Temp, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

Figure 6.10.5.d.2
HOT−245 Red line = Kilo Moana, o = WHOTS−9 Logger #9, x = WHOTS−9 Logger #10

Pressure mbar

ORG Rain Rate mm/hr

ORG Rain accum mm

RM Young Precip mm

Day (2012)

Figure 6.10.5.d.3
HOT-246 Red line = Kilo Moana, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

PSP SW $W/m^2$

PIR LW $W/m^2$

PAR $W/m^2$

Red line = RM Young RTD, Blue line = Humidity Temp, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

Air Temp $^\circ C$

Humidity %

Figure 6.10.5.e.2
Figure 6.10.5.e.3
HOT- 246 Relative Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT- 246 Relative Wind Direction. Blue = ULTRA, Red = RM Young (Port)

HOT- 246 True Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT- 246 True Wind Direction. Blue = ULTRA, Red = RM Young (Port)

Figure 6.10.5.e.4
Figure 6.10.5.f.3
Figure 6.10.5.g.1
Figure 6.10.5.g.2
HOT-248 Red line = Kilo Moana, o = WHOTS-9 Logger #9, x = WHOTS-9 Logger #10

Pressure (mbar)

ORG Rain Rate (mm/hr)

ORG Rain accum (mm)

RM Young Precip (mm)

Day (2012)

Figure 6.10.5.g.3
HOT-248 Relative Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT-248 Relative Wind Direction. Blue = ULTRA, Red = RM Young (Port)

HOT-248 True Wind Speed. Blue = ULTRA, Red = RM Young (Port)

HOT-248 True Wind Direction. Blue = ULTRA, Red = RM Young (Port)

Figure 6.10.5.g.4