Hawaii Ocean Time-series
Data Report 17: 2005

November 2007

Lance A. Fujieki
Fernando Santiago-Mandujano
Paul Lethaby
Roger Lukas
David Karl

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

University of Hawaii
School of Ocean and Earth Science and Technology
1000 Pope Road
Honolulu, Hawaii 96822
U.S.A.
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 2005. However, we have included some data from 1988-2004 to place the 2005 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 2005 cruises sponsored by the HOT program. Special thanks are due to Karin Björkman, Susan Curless, Eric Grabowski, Thomas Gregory, Adriana Harlan, Claire Mahaffey, Dan Sadler, Joseph Shacat and Blake Watkins for the tremendous amount of time and effort they have put into the program. Special thanks are given to Lisa Lum for her excellent administrative support of the program, and Julia Hummon for ADCP processing. Adriana Harlan and Eric Grabowski performed many of the core chemical analyses. Karin Björkman, Susan Curless and Ken Doggett performed the nutrient analyses. Dan Sadler performed the carbon analyses. Joseph Shacat and Suzanne Defelice performed the salinity measurements. Matthew Markley and Melissa Fujimoto performed CTD processing. Brandon Shima and Kellie Terada provided additional technical support. We gratefully acknowledge the support from Nordeen Larson and colleagues at Sea-Bird for helping us to maintain the quality of the CTD data throughout the HOT program. We also would like to thank the captains and crew of the R/V Ka‘imikai-o-Kanaloa, the R/V Kilo Moana, the R/V Wecoma, the R/V Melville 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. Weather buoy data used in this report were obtained by the NOAA National Data Buoy Center (NDBC) and were provided to us by the National Oceanographic Data Center (NODC). We thank Pat Caldwell for his assistance. 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 have supported our 2005 work are NSF grants OCE-0327513 (Lukas) and OCE-0326616 (Karl, Bidigare, Dore, Landry and Letelier).
1.0 INTRODUCTION

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 has 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 focus on the oceanic carbon cycle, its sensitivity to change and the regulation of the atmosphere-ocean CO$_2$ balance (Brewer et al., 1986). The broad objectives of US-JGOFS are:

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

In order to achieve these goals, four separate program elements were defined: (1) process studies to capture key regular events, (2) long-term time-series observations at strategic sites, (3) a global survey of relevant oceanic properties (e.g., CO$_2$), and (4) a vigorous data interpretation and modeling effort to disseminate knowledge and to generate testable hypotheses.

In 1987, two separate proposals were submitted to the US-WOCE and US-JGOFS program committees, respectively, by scientists at the University of Hawaii at Manoa, to establish a multi-disciplinary, deep water hydrostation in proximity to the Hawaiian islands. In July 1988, these proposals were funded by the National Science Foundation and Station ALOHA, the benchmark study site for the Hawaii Ocean Time-series program, was officially on the map (Karl and Lukas 1996). A sister station in the western North Atlantic Ocean, near the historical Panulirus Station, was likewise funded by the US-JGOFS program and is operated by scientists at the Bermuda Biological Station for Research, Inc. (Michaels and Knap 1996).

The primary research objectives of these ocean measurement programs are 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 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 (BEACH) 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 2005

<table>
<thead>
<tr>
<th>Principal Investigators</th>
<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robert R. Bidigare</td>
<td>Phytoplankton community structure</td>
</tr>
<tr>
<td>John E. Dore</td>
<td>BEACH Carbon Component</td>
</tr>
<tr>
<td>David M. Karl</td>
<td>BEACH Core Component</td>
</tr>
<tr>
<td>Michael R. Landry</td>
<td>Zooplankton community structure</td>
</tr>
<tr>
<td>Ricardo M. Letelier</td>
<td>Remote Sensing &amp; Ocean Optics</td>
</tr>
<tr>
<td>Roger B. Lukas</td>
<td>Physical Oceanography Component</td>
</tr>
</tbody>
</table>

1.2 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 objectives specific to the Physical Oceanography program are to:

- Document and understand seasonal and interannual variability of water masses.
- Relate water mass variations to gyre fluctuations.
- Determine the need and methods for monitoring currents at Station ALOHA.
- Develop a climatology of short-term physical variability.

In addition to these general primary objectives, the physical oceanographic component of HOT provides CTD/rosette sampling support for the BEACH time-series sampling program, and supports development of new instrumentation for hydrographic observations.

The objectives of HOT specific to the BEACH program are to:

- 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 2005

<table>
<thead>
<tr>
<th>Principal Investigator(s)</th>
<th>Institution</th>
<th>Agency</th>
<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>John Bullister</td>
<td>PMEL</td>
<td>NSF</td>
<td>CFC and SF₆ geochemistry</td>
</tr>
<tr>
<td>Penny Chisholm</td>
<td>MIT</td>
<td>NSF</td>
<td>Prochlorococcus ecotype dynamics</td>
</tr>
<tr>
<td>Charles Keeling</td>
<td>UCSD Scripps Inst. Oceanography</td>
<td>NSF</td>
<td>¹³C/¹²C ratio of atmosphere carbon dioxide and oceanic carbon in relation to the global carbon cycle</td>
</tr>
<tr>
<td>Paul Quay</td>
<td>Univ. Washington</td>
<td>NOAA</td>
<td>¹³C/¹²C of dissolved inorganic carbon in the ocean</td>
</tr>
</tbody>
</table>

1.3 HOT Study Site

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

We evaluated several major criteria prior to selection of the site for the HOT oligotrophic ocean benchmark hydrostation. First, the station must be located in deep water (>4000 m), upwind (north-northeast) of the main Hawaiian Islands and of sufficient distance from land to be free from coastal ocean dynamics and biogeochemical influences. On the other hand, the station should be close enough to the port of Honolulu to make relatively short duration (<5 d) monthly cruises logistically and financially feasible. A desirable, but less stringent criterion would locate the station at, or near, previously studied regions of the central North Pacific Ocean, in particular Station GOLLUM. Documentation of oceanic time-series measurements in the North Pacific Ocean can be found in Karl and Winn (1991), Karl et al. (1996b), Karl and Lukas (1996) and in the HOT-BEACH web page (hahana.soest.hawaii.edu/hot/hot_jgosf).
After consideration of these criteria, we established our primary sampling site at 22° 45' N, 158° W at a location approximately 100 km north of the island of Oahu (Figure 1.1), and generally restrict our monthly sampling activities to a circle with an 10 km radius around this nominal site (Figure 1.2). Station ALOHA is in deep water (4750 m) and is more than one Rossby radius (50 km) away from steep topography associated with the Hawaiian Ridge. We also established a coastal station WSW of the island of Oahu, approximately 10 km off Kahe Point (21° 20.6' N, 158° 16.4' W) in 1500 m of water. Station Kahe serves as a coastal analogue to our deep-water site and the data collected there provide a near-shore time-series for comparison to our primary open ocean site. Station Kahe is also used to test our equipment each month before departing for Station ALOHA, and to orient new personnel at the beginning of each cruise. From January 1997 to October 2000, a physical-biogeochemical mooring was deployed to obtain continuous measurements of various atmospheric and oceanographic parameters. The mooring was located at 22° 28' N, 158° 8' W and was designated as Station HALE-ALOHA.

In August 2004, 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 is directed toward new technologies that will 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, is 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). Ever since, CTD casts have been taken during various HOT cruises near the mooring for calibration of the moored instruments. This site, named WHOTS is a collaboration with the Woods Hole Oceanographic Institution. It has also been called Station 50. 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. The approach is to maintain a surface mooring by successive mooring turnarounds (Plueddemann, et al., 2006). These observations will be used to investigate air-sea interaction processes related to climate variability.

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).

1.4 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-Kalalau 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, R/V Wecoma, and R/V Melville also have a similar system which was sampled from during 2005.
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.

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

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

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

Water samples for a variety of chemical and biological measurements are routinely collected from the surface to within 10 m of the seafloor. To the extent possible, we collect samples for complementary biogeochemical measurements from the same or from contiguous casts to minimize aliasing caused by time-dependent changes in the density field. This approach is especially important for samples collected in the upper 350 m of the water column. Furthermore, we attempt to sample from common depths and specific density horizons each month to facilitate comparisons between cruises. Water samples for salinity determinations are collected from every water bottle to identify sampling errors. Approximately 20% of the water samples are collected and analyzed in duplicate or triplicate to assess and track our precision in sample analyses.
The HOT program was initially conceived as being a deep ocean, ship and mooring based observation experiment that would have an approximately 20 y lifetime. Consequently, we selected a core suite of environmental variables that might be 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.
Figure 1.2: [Left panels] Drift tracks of the sediment trap array during each HOT cruise in 2005. Starting point of deployment indicated by “S”. [Right panels] CTD cast locations during each HOT cruise in 2005. Location numbers correspond to cast numbers. Dashed line indicates the 10 km radius circle defining the station.
Figure 1.2: continued
HOT-171

Drift

Casts

HOT-172

Drift

Casts

Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
1.5 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>
<thead>
<tr>
<th>Parameter</th>
<th>Depth Range (m)</th>
<th>Analytical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Continuous Measurements</td>
<td></td>
<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>II. Water Column Chemical Measurements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salinity</td>
<td>0-4750</td>
<td>Guildline AutoSal using Wormley seawater standard</td>
</tr>
<tr>
<td>Oxygen</td>
<td>0-4750</td>
<td>Winkler titration</td>
</tr>
<tr>
<td>Dissolved Inorganic Carbon</td>
<td>0-4750</td>
<td>Coulometry</td>
</tr>
<tr>
<td>Total Alkalinity</td>
<td>0-4750</td>
<td>Automated Gran titration</td>
</tr>
<tr>
<td>pH</td>
<td>0-4750</td>
<td>Spectrophotometric</td>
</tr>
<tr>
<td>Nitrate Plus Nitrite</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
</tr>
<tr>
<td>Soluble Reactive Phosphorus (SRP)</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
</tr>
<tr>
<td>Silicate</td>
<td>0-4750</td>
<td>Autoanalyzer</td>
</tr>
<tr>
<td>Low Level Nitrate Plus Nitrite</td>
<td>0-200</td>
<td>Chemiluminescence</td>
</tr>
<tr>
<td>Low Level SRP</td>
<td>0-200</td>
<td>Magnesium-induced coprecipitation</td>
</tr>
<tr>
<td>Dissolved Organic Carbon</td>
<td>0-4750</td>
<td>High temperature catalytic oxidation</td>
</tr>
<tr>
<td>Dissolved Organic Nitrogen</td>
<td>0-1000</td>
<td>UV oxidation of total nitrogen</td>
</tr>
<tr>
<td>Dissolved Organic Phosphorus</td>
<td>0-1000</td>
<td>UV oxidation of total phosphorus</td>
</tr>
<tr>
<td>Particulate Carbon</td>
<td>0-350</td>
<td>High temperature combustion</td>
</tr>
<tr>
<td>-------------------</td>
<td>-------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>Particulate Nitrogen</td>
<td>0-350</td>
<td>High temperature combustion</td>
</tr>
<tr>
<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 with Amonium Molybdate Colorimetry</td>
</tr>
</tbody>
</table>

### III. Biomass Measurements

<table>
<thead>
<tr>
<th>Chlorophyll $a$ and Pheopigments</th>
<th>0-175</th>
<th>Fluorometric analysis using 10-AU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll $a$, $b$ and $c$</td>
<td>0-175</td>
<td>Fluorometric analysis using TD-700</td>
</tr>
<tr>
<td>Pigments</td>
<td>0-175</td>
<td>High Performance Liquid Chromatography (HPLC)</td>
</tr>
<tr>
<td>Phycoerythrin</td>
<td>0-175</td>
<td>Fluorometric analysis using TD-700</td>
</tr>
<tr>
<td>Adenosine 5′-triphosphate</td>
<td>0-350</td>
<td>Firefly bioluminescence</td>
</tr>
<tr>
<td>Bacteria and Cyanobacteria</td>
<td>0-175</td>
<td>Flow cytometry</td>
</tr>
<tr>
<td>Mesozooplankton</td>
<td>0-175</td>
<td>Net tows, elemental analysis</td>
</tr>
</tbody>
</table>

### IV. Carbon Assimilation and Particle Flux

<table>
<thead>
<tr>
<th>Primary Production</th>
<th>0-125</th>
<th>&quot;Clean&quot; $^{14}$C incubations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon, Nitrogen, Phosphorus, Silica</td>
<td>150</td>
<td>Free-floating particle interceptor traps</td>
</tr>
</tbody>
</table>

### V. Currents

| Acoustic Doppler Current Profiler | 10-300 | Hull mounted, RDI #VM-150 |

### VI. Bow Intake System

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

### VII. Optical Measurements

<table>
<thead>
<tr>
<th>Incident Irradiance</th>
<th>Surface</th>
<th>LI-COR LI-1000 and Biospherical collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Downwelling Irradiance</td>
<td>Surface</td>
<td>Biospherical Surface Reference Sensor PRR-610</td>
</tr>
<tr>
<td>Upwelling Radiance and Downwelling Irradiance</td>
<td>0-175</td>
<td>Biospherical Profiling Reflectance Radiometer PRR-600</td>
</tr>
<tr>
<td>Absorption and Beam Attenuation</td>
<td>0-250</td>
<td>WET Labs AC-9 connected to Sea-Bird CTD package</td>
</tr>
<tr>
<td>Fast Repetition Rate Fluorometry</td>
<td>0-250</td>
<td>Chelsea FAST $^{\text{tracka}}$ Dynamic Photosynthetic Fluorometer</td>
</tr>
</tbody>
</table>

### VIII. Moored Instruments

| Sequencing Sediment Traps | 2800, 4000 | Parflux MK7-21 |
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 17th full year of the HOT Program (January-December 2005). During this period, seven regular HOT cruises were conducted using the University of Hawaii research vessels R/V Ō'ā'ō'ā (KOK) and R/V Kilo Moana, two using the Oregon State University vessel R/V Wecoma and one using the Scripps Institution of Oceanography vessel R/V Melville (Table 1.4). University of Hawaii, Oregon State University and Scripps Institution of Oceanography shipboard technical assistance personnel assisted a total field scientific crew of 65 HOT staff, students and visiting scientists (Table 1.5) in our 2005 field work.

Table 1.4: Chronology of 2005 HOT Cruises

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Depart</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td>R/V Wecoma</td>
<td>31 January 2005</td>
<td>4 February 2005</td>
</tr>
<tr>
<td>168</td>
<td>R/V Wecoma</td>
<td>3 March 2005</td>
<td>7 March 2005</td>
</tr>
<tr>
<td>169</td>
<td>R/V Kilo Moana</td>
<td>16 May 2005</td>
<td>20 May 2005</td>
</tr>
<tr>
<td>170</td>
<td>R/V Kilo Moana</td>
<td>13 June 2005</td>
<td>17 June 2005</td>
</tr>
<tr>
<td>171</td>
<td>R/V Melville</td>
<td>15 July 2005</td>
<td>19 July 2005</td>
</tr>
<tr>
<td>172</td>
<td>R/V KOK</td>
<td>12 August 2005</td>
<td>16 August 2005</td>
</tr>
<tr>
<td>173</td>
<td>R/V Kilo Moana</td>
<td>8 September 2005</td>
<td>12 September 2005</td>
</tr>
<tr>
<td>174</td>
<td>R/V Kilo Moana</td>
<td>6 October 2005</td>
<td>11 October 2005</td>
</tr>
<tr>
<td>175</td>
<td>R/V Kilo Moana</td>
<td>10 November 2005</td>
<td>14 November 2005</td>
</tr>
<tr>
<td>176</td>
<td>R/V KOK</td>
<td>11 December 2005</td>
<td>16 December 2005</td>
</tr>
<tr>
<td>Cruise Participants</td>
<td>171</td>
<td>172</td>
<td>173</td>
</tr>
<tr>
<td>---------------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Alvarez, Victoria</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beversdorf, Lucas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Björkman, Karin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bober, Carli</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brandon, Marina</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bullister, John</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chung, Mung Fa</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Church, Matt</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clemente, Tara</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corno, Guido</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curless, Susan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>De Vargas, Colomban</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defelice, Suzanne</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doggett, Ken</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fisher, Pollyanna</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fong, Allison</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fritz, Coutney</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fujieki, Lance</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grabowski, Eric</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grabowski, Marcie</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gregory, Thomas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Guest, Cooper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hannides, Cecelia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hannides, Angelos</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harlan, Adriana</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hayakawa, Darin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hebel, Dale</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hewson, Ian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Huisman, Jef</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jachowski, Nicholas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jameson, Chrystal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kilpatrick, Thomas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landry, Mike</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laney, Sam</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leonard, David</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lethaby, Paul</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liem, Anna</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mahaffey, Claire</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mahdi, Leena</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meier, Sebastian</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cruise Participants</td>
<td>167</td>
<td>168</td>
<td>169</td>
</tr>
<tr>
<td>------------------------------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Menviel, Laurie</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mitchell, James</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mobin, Lena</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mojica, Kristina</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ostrander, Chris</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poretsky, Rachel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rember, Robert</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rognstad, Mark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rosbrugh, Damien</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sadler, Dan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sanchez, Alejandro</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Santiago-Mandujano, Fernando</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shacat, Joseph</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simmons, Melinda</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Smith, Justin</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stal, Lucas</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stomp, Maayke</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stump, Charles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tottori, Steven</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uchikawa, Joji</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Valenciano, Mark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watkins, Blake</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Watkins, Jonathan</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wisegarver, Dave</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Young, Jeremy</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</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 2005 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 #91361 was used during HOT-168 through 171, 174, and 176. CTD #92859 was used during HOT-167, and 171 through 175. CTD # 18987-0568 was used during the second part of HOT-175, after our primary CTD was lost at sea when the CTD wire parted (see Section 3.9, Cruise Summaries).

CTD casts are made at Stations Kahe and ALOHA during each cruise. A CTD cast to 1000 m is made at Station Kahe.

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. 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 all the 2005 cruises except HOT-171. HOT-174 had three deep casts in total.

A CTD cast to 2400 m was conducted at Station Kaena during every 2005 cruise except HOT-168, 169, 172, and 176.

CTD casts have been conducted during cruises near the WHOTS mooring (Station 50), and near the MOSEAN mooring (Station 51) since August 2004, for calibration of the moorings' sensors. Casts to 200-m were conducted at these two stations during 2005 cruises, except that station 50 was not occupied during HOT-168, 171, and 172; and station 51 was not occupied during HOT-168 and 169.

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 Zip™ disks and later onto compact disks. The raw CTD data were quality controlled and screened for spikes as described in Winn et al. (1993). Data alignment, averaging, correction and reporting were done as described in Tupas et al. (1993). Salinity spike rejection parameters were modified for some cruises in 2005 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 167 through 170, and 173 were conducted under relatively rough conditions. The CTD acceleration cutoff value had to be increased to between 0.55 and 0.65 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, is 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 \(\mu\text{mol kg}^{-1}\) and Chloropigment (Fluorescence) in \(\mu\text{g/l}\).

### 2.1.2 Sensor Corrections and Calibrations

#### 2.1.2.1 Pressure

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

##### 2.1.2.1.1 Transfer Standard Calibration

The transfer standard is a Paroscientific Model 760 pressure gauge equipped with a 10,000-PSI transducer. This instrument was purchased in March 1988, and was originally calibrated against a primary standard. Subsequent recalibrations have been performed every 2.5 years on average either at the Northwest Regional Calibration Center or at the Scripps Institute of Oceanography. The latest calibrations were conducted at the Scripps Institute of Oceanography in April 1999, May 2001, May 2003, and July 2005.

##### 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 #75434 (CTD #91361), and #51412 (CTD #92859) are shown in Table 2.1. Tests before September 1998 do not include the 0-dbar offset because problems in the experimental settings during those tests deemed those data unreliable. Sensor #51412 was not calibrated after August 2005 because it was lost at sea in November 2005 (see
Section 3.9, Cruise Summaries). Sensor #75434 suffered an anomaly during HOT-171 when it started displaying decreasing pressures while descending between 300 m and 600 m. The CTD was replaced for the rest of the cruise and the instrument was sent to Sea-Bird for evaluation. Nothing wrong was found with the sensor, and the sensor was recalibrated at Sea-Bird. The sensor has performed correctly since HOT-176.

Pressure transducer #75434 was used during cruises HOT-168 through 171, 174, and 176. Pressure transducer #51412 was used during HOT-167, and 171 through 175. A 1.14 dbar correction was applied to the pressure offset at 0 dbar during data collection for casts conducted with sensor #51412 (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 1.14 dbar offset correction applied to casts with sensor #51412 has been removed in this plot to make it comparable with the data in Table 2.1). The before-cast pressures for both sensors are about 0.3 dbar higher than the 0 dbar offset from the 2005 calibrations (Table 2.1). 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 indicate that our CTD pressure sensors show a decrease of about 0.8 dbar during the first 10 minutes after applying power to the CTD, and the pressure continues to drop a few tenths of a decibar until reaching full stabilization a few hours later. Figure 2.1 indicates that the 0-dbar pressure for sensor #75434 decreased about 0.4 dbar between mid and late 2005, which is confirmed by the calibration tests (Table 2.1).

The mean difference between before-cast and an after-cast on-deck pressure is about 0.3 dbar (Figure 2.1), larger than the hysteresis measured during the bench tests. This on-deck "hysteresis" is actually a residual temperature sensitivity effect of the pressure sensor caused when the CTD is submerged in cold water during casts, which has typical values of the order of 0.5 dbar (Nordeen Larson, personal communication, 1999). Our bench tests do not show this effect because they are conducted at constant room temperature.

The 0-4500 dbar pressure offset and hysteresis from the bench tests have been within expected values and nearly constant for the two sensors. The 0-4500 pressure offset for sensor #51412 suffered a slight increase during 2004-2005. A linear pressure dependent offset is applied during data collection for sensor #51412, to correct for the 0-4500 dbar offset.

Table 2.1: CTD Pressure Calibrations against transfer standard. Offset at 0 dbar for tests before September 1998 are not shown (see text). Sensor’s #75434 August 2005 calibration was performed at Sea-Bird (see text). Units are decibars.

<table>
<thead>
<tr>
<th>Calibration Date</th>
<th>Offset @ 0 dbar</th>
<th>0-4500 dbar offset</th>
<th>Hysteresis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea-Bird SBE-911 Plus #91361 / Pressure Transducer #75434</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26 July 2006</td>
<td>-0.38</td>
<td>0.45</td>
<td>0.11</td>
</tr>
<tr>
<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>Date</td>
<td>Value 1</td>
<td>Value 2</td>
<td>Value 3</td>
</tr>
<tr>
<td>-------------------</td>
<td>---------</td>
<td>---------</td>
<td>---------</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>
<td>0.1</td>
<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>

**Sea-Bird SBE-911 Plus #92859 / Pressure Transducer #51412**

<table>
<thead>
<tr>
<th>Date</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 August 2005</td>
<td>1.22</td>
<td>0.75</td>
<td>0.20</td>
</tr>
<tr>
<td>16 February 2005</td>
<td>1.35</td>
<td>0.75</td>
<td>0.15</td>
</tr>
<tr>
<td>4 July 2004</td>
<td>1.16</td>
<td>0.64</td>
<td>0.15</td>
</tr>
<tr>
<td>10 February 2004</td>
<td>1.28</td>
<td>0.53</td>
<td>0.1</td>
</tr>
<tr>
<td>29 July 2003</td>
<td>1.25</td>
<td>0.55</td>
<td>0.1</td>
</tr>
<tr>
<td>5 February 2003</td>
<td>1.15</td>
<td>0.55</td>
<td>0.1</td>
</tr>
<tr>
<td>17 July 2002</td>
<td>1.2</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>31 January 2002</td>
<td>1.2</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>29 June 2001</td>
<td>1.14</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>5 February 2001</td>
<td>1.1</td>
<td>0.56</td>
<td>0.03</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date</th>
<th>Value 1</th>
<th>Value 2</th>
<th>Value 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 August 2000</td>
<td>1.05</td>
<td>0.6</td>
<td>0.05</td>
</tr>
<tr>
<td>14 January 2000</td>
<td>1.1</td>
<td>0.55</td>
<td>0.05</td>
</tr>
<tr>
<td>25 June 1999</td>
<td>1.0</td>
<td>0.47</td>
<td>0.05</td>
</tr>
<tr>
<td>26 January 1999</td>
<td>0.95</td>
<td>0.55</td>
<td>0.05</td>
</tr>
<tr>
<td>14 September 1998</td>
<td>1.25</td>
<td>0.55</td>
<td>0.05</td>
</tr>
<tr>
<td>12 June 1997</td>
<td>--</td>
<td>0.65</td>
<td>0.05</td>
</tr>
<tr>
<td>31 January 1997</td>
<td>--</td>
<td>0.5</td>
<td>0.08</td>
</tr>
<tr>
<td>30 August 1996</td>
<td>--</td>
<td>0.45</td>
<td>0.01</td>
</tr>
<tr>
<td>5 December 1995</td>
<td>--</td>
<td>0.65</td>
<td>0.07</td>
</tr>
<tr>
<td>21 August 1995</td>
<td>--</td>
<td>0.45</td>
<td>0.05</td>
</tr>
<tr>
<td>16 December 1994</td>
<td>--</td>
<td>0.45</td>
<td>0.05</td>
</tr>
</tbody>
</table>
Figure 2.1: Median value of on-deck pressure measured with the CTD pressure sensors #75434 and #51412, before (circles) and after (crosses) each cast for HOT cruises 167-176. Error bars are one standard deviation from the mean. Cruise numbers are shown below the upper X-axis.
2.1.2.2 Temperature

Four Sea-Bird SBE-3-Plus temperature transducers #2700, #2454, #2454, and #4448 were used in 2005 and were calibrated at Sea-Bird on the dates indicated in Table 2.2. Sensors #2242, and #2700 were not calibrated after October 2005 because they were lost at sea with the CTD during HOT-175 (see Section 3.9, Cruise Summaries). SBE-3-02/F transducer #1489 belongs to the UH Ocean Technology Group, and it was used in some of the casts during HOT-175. Sensor #4448 is a new sensor acquired in November 2005 and used during HOT-176. SBE-3-02/F sensor #1416 was a backup sensor. The history of the sensors, as well as the procedures followed to obtain the sensor drift from the Sea-Bird calibrations are well-documented in Santiago-Mandujano et al. (2002, 2001, 1999), Tupas et al. (1993, 1994a, 1995, 1997, 1998) and Karl et al. (1996). Calibration coefficients obtained at Sea-Bird for these sensors after 2004 and used in the drift estimates are presented in Table 2.2. These coefficients were used in the following formula that gives the temperature (in °C) as a function of the frequency signal (f):

\[
\text{temperature} = \frac{1}{a+b[\ln(f_0/f)]+c[\ln^2(f_0/f)]+d[\ln^3(f_0/f)]} - 273.15
\] (1)

Table 2.2: Calibration coefficients for Sea-Bird temperature sensors. RMS residuals from calibration give an indication of the quality of the calibration. Sensors #2045, #1392, #2078, #3167, #3211, #2490, and #2548 were used in the thermosalinograph (Section 2.2).

<table>
<thead>
<tr>
<th>SN</th>
<th>Date yymmdd</th>
<th>f0</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>RMS (m °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2242</td>
<td>51020</td>
<td>2997.33</td>
<td>3.68121751e-03</td>
<td>6.02947539e-04</td>
<td>1.62210189e-05</td>
<td>2.17306310e-06</td>
<td>0.08</td>
</tr>
<tr>
<td>2242</td>
<td>50827</td>
<td>2997.34</td>
<td>3.68121605e-03</td>
<td>6.02951279e-04</td>
<td>1.62284970e-05</td>
<td>2.17573971e-06</td>
<td>0.07</td>
</tr>
<tr>
<td>2242</td>
<td>50706</td>
<td>2997.34</td>
<td>3.68121499e-03</td>
<td>6.02953872e-04</td>
<td>1.62600888e-05</td>
<td>2.21086408e-06</td>
<td>0.06</td>
</tr>
<tr>
<td>2242</td>
<td>50406</td>
<td>2997.38</td>
<td>3.68121221e-03</td>
<td>6.02941351e-04</td>
<td>1.62151004e-05</td>
<td>2.17196077e-06</td>
<td>0.09</td>
</tr>
<tr>
<td>2242</td>
<td>50111</td>
<td>2997.35</td>
<td>3.68121134e-03</td>
<td>6.02950170e-04</td>
<td>1.62337733e-05</td>
<td>2.17896616e-06</td>
<td>0.07</td>
</tr>
<tr>
<td>2454</td>
<td>60415</td>
<td>2885.75</td>
<td>3.68121439e-03</td>
<td>6.02187499e-04</td>
<td>1.67547819e-05</td>
<td>2.35423435e-06</td>
<td>0.07</td>
</tr>
<tr>
<td>2454</td>
<td>51020</td>
<td>2885.75</td>
<td>3.68121819e-03</td>
<td>6.02183987e-04</td>
<td>1.67711663e-05</td>
<td>2.38731519e-06</td>
<td>0.06</td>
</tr>
<tr>
<td>2454</td>
<td>50827</td>
<td>2885.74</td>
<td>3.68121676e-03</td>
<td>6.02187449e-04</td>
<td>1.67885159e-05</td>
<td>2.40097525e-06</td>
<td>0.05</td>
</tr>
<tr>
<td>2454</td>
<td>50706</td>
<td>2885.74</td>
<td>3.68121551e-03</td>
<td>6.02184381e-04</td>
<td>1.67859182e-05</td>
<td>2.39915470e-05</td>
<td>0.05</td>
</tr>
<tr>
<td>2454</td>
<td>50407</td>
<td>2885.76</td>
<td>3.68121334e-03</td>
<td>6.02186285e-04</td>
<td>1.67971302e-05</td>
<td>2.40912421e-06</td>
<td>0.07</td>
</tr>
<tr>
<td>2454</td>
<td>50111</td>
<td>2885.74</td>
<td>3.68121209e-03</td>
<td>6.02189593e-04</td>
<td>1.68073225e-05</td>
<td>2.41468487e-06</td>
<td>0.07</td>
</tr>
<tr>
<td>2700</td>
<td>51020</td>
<td>2972.60</td>
<td>3.68121843e-03</td>
<td>6.04815410e-04</td>
<td>1.65540507e-05</td>
<td>2.38074221e-06</td>
<td>0.06</td>
</tr>
<tr>
<td>2700</td>
<td>50831</td>
<td>2972.60</td>
<td>3.68121687e-03</td>
<td>6.04816716e-04</td>
<td>1.65592394e-05</td>
<td>2.38239620e-06</td>
<td>0.04</td>
</tr>
<tr>
<td>2700</td>
<td>50706</td>
<td>2972.61</td>
<td>3.68121552e-03</td>
<td>6.04817663e-04</td>
<td>1.65641164e-05</td>
<td>2.38432603e-05</td>
<td>0.05</td>
</tr>
<tr>
<td>2700</td>
<td>50406</td>
<td>2972.64</td>
<td>3.68121334e-03</td>
<td>6.04819001e-04</td>
<td>1.65681867e-05</td>
<td>2.39213534e-05</td>
<td>0.08</td>
</tr>
<tr>
<td>2700</td>
<td>50111</td>
<td>2972.60</td>
<td>3.68121232e-03</td>
<td>6.04822192e-04</td>
<td>1.65825571e-05</td>
<td>2.39934333e-05</td>
<td>0.08</td>
</tr>
<tr>
<td>4448</td>
<td>60415</td>
<td>2872.31</td>
<td>3.68121431e-03</td>
<td>5.97077412e-04</td>
<td>1.50501277e-05</td>
<td>1.81399552e-06</td>
<td>0.06</td>
</tr>
<tr>
<td>4448</td>
<td>51110</td>
<td>2872.34</td>
<td>3.68121770e-03</td>
<td>5.97041275e-04</td>
<td>1.49263547e-05</td>
<td>1.72296669e-06</td>
<td>0.01</td>
</tr>
<tr>
<td>1416</td>
<td>60415</td>
<td>6234.23</td>
<td>3.68121350e-03</td>
<td>6.01728143e-04</td>
<td>1.46914012e-05</td>
<td>1.83552453e-06</td>
<td>0.21</td>
</tr>
<tr>
<td>1416</td>
<td>51025</td>
<td>6234.31</td>
<td>3.68121160e-03</td>
<td>6.01777975e-04</td>
<td>1.48245951e-05</td>
<td>1.94706458e-06</td>
<td>0.21</td>
</tr>
<tr>
<td>1416</td>
<td>50831</td>
<td>6234.35</td>
<td>3.68121079e-03</td>
<td>6.01750449e-04</td>
<td>1.47627395e-05</td>
<td>1.90930336e-05</td>
<td>0.19</td>
</tr>
<tr>
<td>1416</td>
<td>50706</td>
<td>6234.36</td>
<td>3.68121149e-03</td>
<td>6.01771356e-04</td>
<td>1.48208516e-05</td>
<td>1.95311206e-06</td>
<td>0.20</td>
</tr>
<tr>
<td>1416</td>
<td>50405</td>
<td>6234.37</td>
<td>3.68121115e-03</td>
<td>6.01765956e-04</td>
<td>1.48156960e-05</td>
<td>1.95096507e-06</td>
<td>0.22</td>
</tr>
</tbody>
</table>
### Table 2.3

<table>
<thead>
<tr>
<th>Date</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>040812</td>
<td>3.68121511e-03</td>
</tr>
<tr>
<td>041028</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>050225</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>051208</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>060704</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>061003</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>061205</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>070101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>070303</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>080101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>080303</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>090101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>090303</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>100101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>100301</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>110101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>110301</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>120101</td>
<td>3.68121154e-03</td>
</tr>
<tr>
<td>120301</td>
<td>3.68121154e-03</td>
</tr>
</tbody>
</table>

For each sensor, the final calibration consists of two parts: first, a single "baseline" calibration is chosen from among the ensemble of calibrations during the year; second, for each cruise a temperature-independent offset is applied to remove the temporal trend due to sensor drift (Table 2.3). The offset, a linear function of time, is calculated by least squares fit to the 0-30 °C average of each calibration during the year. The maximum drift correction in 2005 was less
than 0.2 x $10^{-3}$ °C for the data collected with these sensors, the only exception was sensor #1489 used in some casts during HOT-175, for these casts the temperature drift correction was 0.9 x $10^{-3}$ °C. 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 2005 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 2005 cruises, showing temperature differences within expected values. The mean temperature difference as a function of pressure was typically less than 1 x $10^{-3}$ °C, with a standard deviation of less than 0.5 x $10^{-3}$ °C below 500 dbar. The largest variability was observed in the thermocline, with standard deviation values of up to 5 x $10^{-3}$ °C.

**Sensor #2454**

The calibrations from October 2002 through April 2006 indicated a change in the sensor's drift starting in September 2004. The calibrations after this date were used to estimate a sensor drift of $-6.1 \times 10^{-7}$ °C day$^{-1}$ with an intercept of $-1.6 \times 10^{-4}$ °C and a RMS residual of $1.8 \times 10^{-4}$ °C, and was used to obtain the drift correction for cruises HOT-167 through 171, 175, and 176. When corrected for linear drift to 30 June 2005 (the mid-date when the sensor was used), the 6 July 2005 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 30 June 2005). Drift corrections were obtained using this calibration as a baseline. The deviation was $-4 \times 10^{-7}$ °C with less than 0.1 x $10^{-4}$ °C range of variation. The set of all calibrations had deviations in the range ± 6 x $10^{-4}$ °C. The resulting drift corrections for each cruise were less than 0.1 x $10^{-3}$ °C, and deemed insignificant (Table 2.3).

**Sensor #2700**

The calibrations from January 2003 through October 2005 were used to estimate a sensor drift of $-6.54 \times 10^{-7}$ °C day$^{-1}$ with an intercept of $1.5 \times 10^{-4}$ °C and a RMS residual of $1.8 \times 10^{-4}$ °C. This drift was used to obtain the correction for cruises HOT-167 through 175. When corrected for linear drift to 30 May 2005 (the midpoint of the cruise dates), the 20 October 2005 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of calibrations obtained in 2005 (also corrected for linear drift to 30 May 2005). The deviation was $-1.68 \times 10^{-6}$ °C with less than 0.1 x $10^{-4}$ °C range of variation. The set of all calibrations had deviations in the range ± 6 x $10^{-4}$ °C. The resulting drift corrections for each cruise were less than 0.2 x $10^{-3}$ °C, and deemed insignificant (Table 2.3).
Sensor #2242

The calibrations from March 2003 through October 2005 were used to estimate a sensor drift of $6.56 \times 10^{-7} \, ^\circ C \, day^{-1}$ with an intercept of $-2.3 \times 10^{-4} \, ^\circ C$ and a RMS residual of $2 \times 10^{-4} \, ^\circ C$. This drift was used to obtain the correction for cruises HOT-172 through 175. When corrected for linear drift to 30 September 2005 (the midpoint of the cruise dates), the 6 July 2005 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of calibrations obtained in 2005 (also corrected for linear drift to 30 September 2005). The deviation was $-1.2 \times 10^{-6} \, ^\circ C$ with less than $0.2 \times 10^{-4} \, ^\circ C$ range of variation. The set of all calibrations had deviations in the range ± $7 \times 10^{-4} \, ^\circ C$. The resulting drift corrections for each cruise were less than $0.1 \times 10^{-3} \, ^\circ C$, and deemed insignificant (Table 2.3).

Sensor #4448

This is a new sensor acquired in November 2005, and it only has been calibrated two times, in November 2005, and April 2006. These two calibrations were used to estimate a sensor drift of $4.81 \times 10^{-6} \, ^\circ C \, day^{-1}$. This drift was used to obtain the correction for cruise HOT-176. When corrected for linear drift to 14 December 2005 (the midpoint of the cruise dates), the 10 November 2005 calibration gave the smallest deviation in the 0-5 °C temperature range from the two calibrations (also corrected for linear drift to 14 December 2005). The deviation was $-5.2 \times 10^{-5} \, ^\circ C$ with less than $0.7 \times 10^{-4} \, ^\circ C$ range of variation. The set of all calibrations had deviations in the range ± $2 \times 10^{-4} \, ^\circ C$. The resulting drift correction for HOT-176 was less than $0.2 \times 10^{-3} \, ^\circ C$, and deemed insignificant (Table 2.3).

Sensor #1489

This sensor belongs to the UH Ocean Technology Group, and it was used during HOT-175. The January 2003, December 2004, and December 2005 calibrations were used to estimate a sensor drift of $3.25 \times 10^{-6} \, ^\circ C \, day^{-1}$ with an intercept of $-3.7 \times 10^{-4} \, ^\circ C$ and a RMS residual of $2.7 \times 10^{-4} \, ^\circ C$. This drift was used to obtain the correction for cruise HOT-175. When corrected for linear drift to 15 November 2005 (the midpoint of the cruise dates), the 2 December 2004 calibration gave the smallest deviation in the 0-5 °C temperature range from the two calibrations (also corrected for linear drift to 15 November 2005). The deviation was $3.6 \times 10^{-4} \, ^\circ C$ with less than $0.4 \times 10^{-4} \, ^\circ C$ range of variation. The set of all calibrations had deviations in the range ± $8 \times 10^{-4} \, ^\circ C$. The resulting drift correction for HOT-175 was about $1 \times 10^{-3} \, ^\circ C$, this correction was applied to the data obtained during the cruise (Table 2.3).

Sensor #1416

This sensor was not used during 2005. This sensor has maintained a constant and uninterrupted drift for a long time. The calibrations between October 2002 and April 2006 yielded a linear drift of $1.45 \times 10^{-6} \, ^\circ C \, day^{-1}$, with an intercept of $1.2 \times 10^{-4} \, ^\circ C$, and $1.3 \times 10^{-4} \, ^\circ C$ RMS residuals.
Table 2.3: Temperature (T) and Conductivity (C) sensor corrections including the thermal inertia parameter (α). 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>α</th>
<th>Data reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>2700</td>
<td>0.000170</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-167</td>
<td>2454</td>
<td>0.000095</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-168</td>
<td>2700</td>
<td>0.000150</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-168</td>
<td>2454</td>
<td>0.000076</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-169</td>
<td>2700</td>
<td>0.000101</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-169</td>
<td>2454</td>
<td>0.000030</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-170</td>
<td>2700</td>
<td>0.000083</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-170</td>
<td>2454</td>
<td>0.000013</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-171</td>
<td>2700</td>
<td>0.000062</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-171</td>
<td>2454</td>
<td>-0.000007</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-172</td>
<td>2700</td>
<td>0.000044</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-172</td>
<td>2242</td>
<td>0.000026</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-173</td>
<td>2700</td>
<td>0.000026</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-173</td>
<td>2242</td>
<td>0.000043</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-174</td>
<td>2700</td>
<td>0.000005</td>
<td>2725</td>
<td>0.020</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-174</td>
<td>2242</td>
<td>0.000062</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-175</td>
<td>2700</td>
<td>-0.000015</td>
<td>2725</td>
<td>0.020</td>
<td>s1c1,s 2c1-6</td>
</tr>
<tr>
<td>HOT-175</td>
<td>2242</td>
<td>-0.000085</td>
<td>2541</td>
<td>0.020</td>
<td></td>
</tr>
<tr>
<td>HOT-175</td>
<td>2454</td>
<td>0.000080</td>
<td>2218</td>
<td>0.028</td>
<td>All other casts</td>
</tr>
<tr>
<td>HOT-175</td>
<td>1489</td>
<td>0.000923</td>
<td>1178</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-176</td>
<td>2454</td>
<td>-0.000099</td>
<td>2218</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>HOT-176</td>
<td>4448</td>
<td>0.000164</td>
<td>3162</td>
<td>0.028</td>
<td>All casts</td>
</tr>
</tbody>
</table>

2.1.2.3 Conductivity

Five conductivity sensors were used during the 2005 cruises #2725, #2541, #2218, #1178, and #3162. Sensors #2725 and #2541 were lost at sea when the CTD wire broke during HOT-175. Sensor #1178 belongs to the UH Ocean Technology Group, and it was used in some casts during HOT-175. Sensor #3162 is a new sensor acquired in November 2005 and used during HOT-176. The history of the sensors is well documented in Santiago-Mandujano et al. (2002, 2001, 1999), Tupas et al. (1993, 1994a, 1995, 1997, 1998) and 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 α parameter used for each cruise.
Procedures for preliminary screening of bottle samples and empirical calibration of the conductivity cell are described in Tupas et al. (1993, 1994a). For cruises HOT-167 through -176, the standard deviation cutoff values for screening of bottle salinity samples were: 0.0036 (0-150 dbar), 0.0049 (151-500 dbar), 0.0020 (501-1050 dbar), and 0.0011 (1051-5000 dbar).

The conductivity calibration coefficients \(b_0, b_1, b_2\) derived from the least squares fit \(\Delta C = b_0 + b_1 C + b_2 C^2\) to the CTD-bottle conductivity differences \(\Delta C\) as a function of conductivity \(C\) are given in Table 2.4. One cruise during 2005 required a quadratic calibration (HOT-175). 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-167</td>
<td>2725</td>
<td>0.000708</td>
<td>-0.000183</td>
<td></td>
</tr>
<tr>
<td>HOT-167</td>
<td>2541</td>
<td>0.000628</td>
<td>-0.000182</td>
<td></td>
</tr>
<tr>
<td>HOT-168</td>
<td>2725</td>
<td>0.000444</td>
<td>-0.000069</td>
<td></td>
</tr>
<tr>
<td>HOT-168</td>
<td>2541</td>
<td>0.000456</td>
<td>-0.000083</td>
<td></td>
</tr>
<tr>
<td>HOT-169</td>
<td>2725</td>
<td>0.000452</td>
<td>-0.000088</td>
<td></td>
</tr>
<tr>
<td>HOT-169</td>
<td>2541</td>
<td>0.000287</td>
<td>-0.000051</td>
<td></td>
</tr>
<tr>
<td>HOT-170</td>
<td>2725</td>
<td>0.000645</td>
<td>-0.000144</td>
<td></td>
</tr>
<tr>
<td>HOT-170</td>
<td>2541</td>
<td>0.000540</td>
<td>-0.000118</td>
<td></td>
</tr>
<tr>
<td>HOT-171</td>
<td>2725</td>
<td>0.000597</td>
<td>-0.000122</td>
<td></td>
</tr>
<tr>
<td>HOT-171</td>
<td>2541</td>
<td>0.000456</td>
<td>-0.000080</td>
<td></td>
</tr>
<tr>
<td>HOT-172</td>
<td>2725</td>
<td>0.000374</td>
<td>-0.000080</td>
<td></td>
</tr>
<tr>
<td>HOT-172</td>
<td>2541</td>
<td>0.000316</td>
<td>-0.000047</td>
<td></td>
</tr>
<tr>
<td>HOT-173</td>
<td>2725</td>
<td>0.000383</td>
<td>-0.000093</td>
<td></td>
</tr>
<tr>
<td>HOT-173</td>
<td>2541</td>
<td>0.000330</td>
<td>-0.000061</td>
<td></td>
</tr>
<tr>
<td>HOT-174</td>
<td>2725</td>
<td>0.000551</td>
<td>-0.000170</td>
<td></td>
</tr>
<tr>
<td>HOT-174</td>
<td>2541</td>
<td>0.000466</td>
<td>-0.000120</td>
<td></td>
</tr>
<tr>
<td>HOT-175</td>
<td>2725</td>
<td>0.000532</td>
<td>-0.000170</td>
<td></td>
</tr>
<tr>
<td>HOT-175</td>
<td>2218</td>
<td>0.004828</td>
<td>-0.002278</td>
<td>0.000242</td>
</tr>
<tr>
<td>Cruise</td>
<td>Station</td>
<td>Cast</td>
<td>C Correction</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>---------</td>
<td>------</td>
<td>--------------</td>
<td></td>
</tr>
<tr>
<td>HOT-176</td>
<td>2</td>
<td>3</td>
<td>0.000239</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>Sensor #</th>
<th>Mean</th>
<th>St. dev</th>
<th>Mean</th>
<th>St. dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>2725</td>
<td>-0.0000</td>
<td>0.0022</td>
<td>0.0001</td>
<td>0.0011</td>
</tr>
<tr>
<td>HOT-167</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0024</td>
<td>0.0005</td>
<td>0.0010</td>
</tr>
<tr>
<td>HOT-168</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0028</td>
<td>0.0003</td>
<td>0.0010</td>
</tr>
<tr>
<td>HOT-168</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0026</td>
<td>0.0004</td>
<td>0.0010</td>
</tr>
<tr>
<td>HOT-169</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0026</td>
<td>0.0002</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-169</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0025</td>
<td>0.0004</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-170</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0027</td>
<td>0.0002</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-170</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0028</td>
<td>0.0004</td>
<td>0.0015</td>
</tr>
<tr>
<td>HOT-171</td>
<td>2725</td>
<td>-0.0000</td>
<td>0.0024</td>
<td>-0.0002</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-171</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0026</td>
<td>0.0000</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-172</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0022</td>
<td>0.0003</td>
<td>0.0010</td>
</tr>
<tr>
<td>HOT-172</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0023</td>
<td>0.0007</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-173</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0024</td>
<td>-0.0000</td>
<td>0.0015</td>
</tr>
<tr>
<td>HOT-173</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0025</td>
<td>0.0003</td>
<td>0.0014</td>
</tr>
<tr>
<td>HOT-174</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0026</td>
<td>0.0002</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-174</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0023</td>
<td>0.0004</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-175</td>
<td>2725</td>
<td>0.0000</td>
<td>0.0017</td>
<td>0.0001</td>
<td>0.0012</td>
</tr>
<tr>
<td>HOT-175</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0026</td>
<td>0.0001</td>
<td>0.0018</td>
</tr>
<tr>
<td>HOT-175</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0019</td>
<td>0.0003</td>
<td>0.0011</td>
</tr>
<tr>
<td>HOT-175</td>
<td>1178</td>
<td>0.0000</td>
<td>0.0035</td>
<td>-0.0003</td>
<td>0.0032</td>
</tr>
<tr>
<td>HOT-176</td>
<td>2218</td>
<td>-0.0001</td>
<td>0.0028</td>
<td>0.0001</td>
<td>0.0020</td>
</tr>
<tr>
<td>HOT-176</td>
<td>3162</td>
<td>-0.0003</td>
<td>0.0037</td>
<td>-0.0001</td>
<td>0.0024</td>
</tr>
</tbody>
</table>

Table 2.6: CTD-Bottle salinity comparison for each cruise
Figure 2.2: Difference between calibrated CTD salinities and bottle salinities for each cruise and all casts at Station ALOHA in 2005.
2.1.2.4 Oxygen

During the 2005 cruises our three Sea-Bird SBE-43 oxygen sensors were used: #43134, #43262, and #43325, in addition sensor #43019 belonging to the UH Ocean Technology Group was also used during HOT-175. Sensors #43134 and #43325 were lost at sea when the CTD wire broke during HOT-175. A new sensor #43918 was acquired in November, 2005 and used during HOT-176. The history of these sensors is documented in Santiago-Mandujano et al. (2002, 2001, 1999). Sensor's #43262 membrane was found punctured during a routine calibration at Sea-Bird in August 2005 and was repaired. Sensor’s #43134 membrane was also found punctured in an October 2005 calibration. These sensors had their lid and membrane assembly replaced at Sea-Bird, as well as their electrolyte reservoir re-backfilled.

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 51). 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>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>43325</td>
<td>0.00</td>
<td>0.59</td>
</tr>
<tr>
<td>HOT-168</td>
<td>43325</td>
<td>0.00</td>
<td>0.56</td>
</tr>
<tr>
<td>HOT-169</td>
<td>43325</td>
<td>0.00</td>
<td>0.51</td>
</tr>
<tr>
<td>HOT-170</td>
<td>43325</td>
<td>0.00</td>
<td>0.58</td>
</tr>
<tr>
<td>HOT-171</td>
<td>43325</td>
<td>0.00</td>
<td>0.88</td>
</tr>
<tr>
<td>HOT-172</td>
<td>43325</td>
<td>0.00</td>
<td>0.98</td>
</tr>
<tr>
<td>HOT-173</td>
<td>43325</td>
<td>0.01</td>
<td>0.62</td>
</tr>
<tr>
<td>HOT-174</td>
<td>43262</td>
<td>0.00</td>
<td>0.43</td>
</tr>
<tr>
<td>HOT-175</td>
<td>43325</td>
<td>0.00</td>
<td>0.51</td>
</tr>
<tr>
<td>HOT-176</td>
<td>43918</td>
<td>0.00</td>
<td>1.06</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-167</td>
<td>43325</td>
<td>0.01</td>
<td>0.89</td>
<td>-0.05</td>
<td>0.82</td>
</tr>
<tr>
<td>HOT-168</td>
<td>43325</td>
<td>0.01</td>
<td>0.89</td>
<td>-0.04</td>
<td>0.70</td>
</tr>
<tr>
<td>HOT-169</td>
<td>43325</td>
<td>0.04</td>
<td>0.71</td>
<td>0.01</td>
<td>0.61</td>
</tr>
<tr>
<td>HOT-170</td>
<td>43325</td>
<td>0.01</td>
<td>0.74</td>
<td>-0.01</td>
<td>0.54</td>
</tr>
<tr>
<td>HOT-171</td>
<td>43325</td>
<td>0.01</td>
<td>1.01</td>
<td>0.04</td>
<td>0.90</td>
</tr>
<tr>
<td>HOT-172</td>
<td>43325</td>
<td>0.00</td>
<td>0.77</td>
<td>0.01</td>
<td>0.59</td>
</tr>
<tr>
<td>HOT-173</td>
<td>43325</td>
<td>0.01</td>
<td>0.79</td>
<td>-0.03</td>
<td>0.67</td>
</tr>
<tr>
<td>HOT-174</td>
<td>43262</td>
<td>0.00</td>
<td>0.60</td>
<td>-0.01</td>
<td>0.48</td>
</tr>
<tr>
<td>HOT-175</td>
<td>43325</td>
<td>0.00</td>
<td>0.53</td>
<td>0.00</td>
<td>0.55</td>
</tr>
<tr>
<td>HOT-176</td>
<td>43918</td>
<td>0.01</td>
<td>0.72</td>
<td>0.02</td>
<td>0.74</td>
</tr>
</tbody>
</table>

2.1.2.5 Fluorescence (Chloropigment)

Fluorescence was measured with a Sea-Point chlorophyll fluorometer (#2440 and #2441). The data was collected using the Sea-Bird CTD system. Fluorescence traces were collected on as many casts as possible. Because an absolute radiometric standard is not available for fluorometers, instrument drift was corrected via calibration with bottle fluorometric chlorophyll a plus accessory pheopigments analyzed using a Turner Designs Model 10-AU fluorometer as described in Section 2.5.6.1. A linear relationship of the form, \( V_{chl} = b \cdot V_{fluor} + a \), was used to convert all fluorescence data to chloropigment.
2.1.3 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 ± 0.001 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. Secondary standard batches #35, 36, 37, and 38 were prepared on August 28, 2004; February 24, 2005; June 29, 2005; and on November 21, 2005, respectively.

Table 2.8: Precision of salinity measurements using secondary lab standards

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Mean Salinity ± SD</th>
<th># Samples</th>
<th>Substandard Batch #</th>
<th>IAPSO Batch #</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>34.46390±0.00046</td>
<td>26</td>
<td>35</td>
<td>P144</td>
</tr>
<tr>
<td>HOT-168</td>
<td>34.45614±0.00037</td>
<td>37</td>
<td>36</td>
<td>P144</td>
</tr>
<tr>
<td>HOT-169</td>
<td>34.45552±0.00040</td>
<td>39</td>
<td>36</td>
<td>P144</td>
</tr>
<tr>
<td>HOT-170</td>
<td>34.45516±0.00056</td>
<td>28</td>
<td>36</td>
<td>P144</td>
</tr>
<tr>
<td>HOT-171</td>
<td>34.47666±0.00032</td>
<td>36</td>
<td>37</td>
<td>P144</td>
</tr>
<tr>
<td>HOT-172</td>
<td>34.47622±0.00017</td>
<td>22</td>
<td>37</td>
<td>P145</td>
</tr>
<tr>
<td>HOT-173</td>
<td>34.47624±0.00029</td>
<td>31</td>
<td>37</td>
<td>P145</td>
</tr>
<tr>
<td>HOT-174</td>
<td>34.47643±0.00031</td>
<td>26</td>
<td>37</td>
<td>P145</td>
</tr>
<tr>
<td>HOT-175</td>
<td>34.49206±0.00029</td>
<td>33</td>
<td>38</td>
<td>P145</td>
</tr>
<tr>
<td>HOT-176</td>
<td>34.49282±0.00031</td>
<td>31</td>
<td>38</td>
<td>P145</td>
</tr>
</tbody>
</table>

2.2 Thermosalinograph

2.2.1 Data Acquisition

Continuous near-surface salinity and temperature data were collected during every 2005 HOT cruise (HOT-167 through HOT-176) using Sea-Bird thermosalinograph and temperature sensors aboard the R/V Wecoma, R/V Kaʻimikai-O-Kanaloa, R/V Melville and the R/V Kilo Moana. The details of each thermosalinograph system varied from ship to ship, but every system was composed of a remote temperature sensor to measure near-surface temperatures at the intake of the ship's uncontaminated seawater supply in conjunction with a thermosalinograph sensor that measured both conductivity and temperature. Salinity of the seawater was then calculated using the internal temperature and conductivity as well as the internal pressure of the pump. The 2005 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 bottle salinities samples periodically taken (approximately every 4 hours) from the continuous seawater line outtake near to the thermosalinograph. The thermosalinograph data from each cruise were also compared with the CTD temperature and conductivity data collected at the same time and from near the same depth as the thermosalinograph data for a finals data quality control.

Table 2.9: 2005 HOT Cruise Thermosalinograph Sensors

<table>
<thead>
<tr>
<th>HOT Cruise No.</th>
<th>Ship</th>
<th>Sensor S/N</th>
<th>Remote T</th>
<th>Internal T and C</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>W</td>
<td>2490</td>
<td>2548</td>
<td></td>
</tr>
<tr>
<td>HOT-168</td>
<td>W</td>
<td>2490</td>
<td>2548</td>
<td></td>
</tr>
<tr>
<td>HOT-169</td>
<td>KM</td>
<td>0150</td>
<td>3167</td>
<td></td>
</tr>
<tr>
<td>HOT-170</td>
<td>KM</td>
<td>0150</td>
<td>3167</td>
<td></td>
</tr>
<tr>
<td>HOT-171</td>
<td>M</td>
<td>-</td>
<td>0067</td>
<td></td>
</tr>
<tr>
<td>HOT-172</td>
<td>KOK</td>
<td>1496/2078</td>
<td>1392/2045/1392</td>
<td></td>
</tr>
<tr>
<td>HOT-173</td>
<td>KM</td>
<td>0150</td>
<td>3167</td>
<td></td>
</tr>
<tr>
<td>HOT-174</td>
<td>KM</td>
<td>0169</td>
<td>3211</td>
<td></td>
</tr>
<tr>
<td>HOT-175</td>
<td>KM</td>
<td>0169</td>
<td>3211</td>
<td></td>
</tr>
<tr>
<td>HOT-176</td>
<td>KOK</td>
<td>2078</td>
<td>2045</td>
<td></td>
</tr>
</tbody>
</table>

M = R/V Melville
KOK = R/V Ka'imikai-O-Kanaloa
KM = R/V Kilo Moana
W = R/V Wecoma

The thermosalinograph system aboard the R/V Wecoma consisted of a SBE-4 conductivity sensor in conjunction with an internal SBE-3 temperature sensor located in the wet lab, along with a SBE-3 external temperature sensor located close to the seawater intake. The depth of the intake was approximately 4 meters below the surface and the internal pressure of the pump was 10 dbar. Data were acquired every 60 seconds.

The thermosalinograph system aboard the R/V Kilo Moana consisted of an internal SBE-21 Seacat thermosalinograph unit along with a SBE-38 external temperature sensor installed in the bowthruster chamber close to the seawater intake. The depth of the intake was 8 meters below the surface, and the internal pressure of the pump was 6 dbar. The external temperature sensor was situated just aft of the seawater intake pump and the resultant water temperatures were higher than values obtained with the CTD at the same depth as the intake and bucket temperature measurements made at the intake. External temperature data for HOT-169, 170, 173, 174, and 175 were adjusted using the 8dbar CTD measurements and subsequently flagged as uncalibrated. Data were acquired every 10 seconds.

The thermosalinograph system aboard the R/V Melville consisted of a internal SBE-45 Seacat thermosalinograph unit with an additional SBE-38 temperature sensor located in the analytical lab. External temperature measurements were made with two hull mounted sensors,
the make and model of the sensors was unknown. The depth of the seawater intake was approximately 4 meters below the surface, and the internal pressure of the pump was 10 dbar. It is not certain when the hull mounted temperature sensors were last calibrated and resultant temperatures were lower than values obtained with the CTD at the same depth as the intake and bucket temperature measurements made at the intake. Temperature data from the SBE-45 were used in place of the hull mounted temperature sensors and the additional temperature sensor near the thermosalinograph, and were adjusted using the 4 dbar CTD temperature data and subsequently flagged as uncalibrated. Data were acquired every 30 seconds.

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 seachest 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 above) have been calibrated at Sea-Bird. Since sensors #2490, #2548, #2078, #3167, #1392, #3211, and #2045 are the same type as used for the CTD measurements, the same procedure for drift estimation was followed (see Section 2.1.2.2). The data taken with sensor #1496 during HOT-172 were faulty and not reported (see Section 2.2.2.2), thus a drift estimation for this sensor was not performed.

A temperature drift rate of $-1.55 \times 10^{-7} \, ^\circ$C day$^{-1}$ was determined for remote temperature sensor #2490 using the 28 October 2004 and 4 July 2006 calibrations (Table 2.2). Temperatures were calculated with the 28 October 2004 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $-1.61 \times 10^{-6} \, ^\circ$C day$^{-1}$ was determined for remote temperature sensor #2548 using the 12 August 2004 and 13 September 2005 calibrations (Table 2.2). Temperatures were calculated with the 12 August 2004 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $1.68 \times 10^{-6} \, ^\circ$C day$^{-1}$ was determined for remote temperature sensor #2078 using the 08 September 2000, 30 June 2001, 30 January 2002, 27 February 2003, 30 June 2004, and 3 March 2006 calibrations (Table 2.2). Temperatures were calculated with the 30 January 2002 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $-1.91 \times 10^{-7} \, ^\circ$C day$^{-1}$ was determined for remote temperature sensor #3167 using the 9 February 2002, 24 January 2003, 10 December 2003, and 21 September 2005 calibrations (Table 2.2). Temperatures were calculated with the 10 December
2003 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $3.46 \times 10^{-7}$ °C day$^{-1}$ was determined for internal temperature sensor #1392 using the 20 August 1997, 28 August 1997, 27 January 2000, 27 January 2002, 03 June 2003, 02 July 2004, and 07 October 2005 calibrations (Table 2.2). Temperatures were calculated with the 02 July 2004 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $-3.13 \times 10^{-7}$ °C day$^{-1}$ was determined for remote temperature sensor #3211 using the 21 February 2003, 25 February 2005, and 8 December 2005 calibrations (Table 2.2). Temperatures were calculated with the 21 February 2003 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

A temperature drift rate of $-2.42 \times 10^{-7}$ °C day$^{-1}$ was determined for internal temperature sensor #2045 using the 11 October 1995, 30 July 1996, 28 July 1998, 10 August 1999, 08 September 2000, 30 June 2001, 24 January 2003, 17 March 2004, 12 October 2004, 16 September 2005, and 03 October 2006 calibrations (Table 2.2). Temperatures were calculated with the 16 September 2005 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

Temperature sensors #0169 and #150 are SBE-38 model, and sensor #0067 is a SBE-45 model. These sensors use the following equation to convert the instrument output (n) to temperature (in °C):

$$temperature = 1/[a0+a1[ln(n)]+a2[ln^2(n)]+a3[ln^3(n)]]-273.15$$

A temperature drift rate of $-7.82 \times 10^{-7}$ °C day$^{-1}$ was determined for internal temperature sensor #0067 using the 01 January 2003, 06 January 2004, 17 November 2004, and 10 January 2006 calibrations (Table 2.10). Temperatures were calculated with the 02 July 2004 baseline calibration. Drift corrections were not applied to the data for this sensor, as they are very small and inconsequential.

Drift rates were not determined for SBE-38 temperature sensors #0150 (used during HOT-169, 170, and 173), and #0169 (used during HOT-174 and 175), as temperature data were adjusted using 8 dbar CTD temperature data and flagged as uncalibrated due to heating from the pump, (see Section 2.2.1 above).
Table 2.10: Calibration coefficients for Sea-Bird temperature sensors SBE-38. RMS residuals from calibration give an indication of the quality of calibration.

<table>
<thead>
<tr>
<th>SN</th>
<th>Date yymmd</th>
<th>(a0)</th>
<th>(a1)</th>
<th>(a2)</th>
<th>(a3)</th>
<th>RMS (m°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0067</td>
<td>060110</td>
<td>-9.92101900e-05</td>
<td>2.91139700e-04</td>
<td>-3.39340300e-06</td>
<td>1.84128400e-07</td>
<td>0.00</td>
</tr>
<tr>
<td>0067</td>
<td>041117</td>
<td>-6.58762300e-05</td>
<td>2.83545900e-04</td>
<td>-2.81594600e-06</td>
<td>1.69469100e-07</td>
<td>0.07</td>
</tr>
<tr>
<td>0067</td>
<td>040106</td>
<td>-5.88942800e-05</td>
<td>2.81752500e-04</td>
<td>-2.66424200e-06</td>
<td>1.65231200e-07</td>
<td>0.08</td>
</tr>
<tr>
<td>0067</td>
<td>030101</td>
<td>-8.58416500e-05</td>
<td>2.88132500e-04</td>
<td>-3.16764600e-06</td>
<td>1.78466800e-07</td>
<td>0.10</td>
</tr>
</tbody>
</table>

2.2.2.1.2 Conductivity

Seven different conductivity sensors were used to collect thermosalinograph data for the 2005 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.

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 a total of 2 gross errors detected in temperature and no gross errors detected in conductivity during the ten 2005 HOT cruises, with a typical cruise containing approximately 30,000-40,000 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, 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 conduct glitches in the thermosalinograph data. Glitches in temperature and conductivity detected by the 5-point median filter were immediately replaced by the median. Threshold values of 0.3 °C for temperature and 0.1 Siemens m\(^{-1}\) for conductivity were used for the median filter. No more than a few points were 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 92 to 2746, with the majority of the flags applied to the conductivity data. Most sections of flagged data were relatively small and were 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 large periods of suspect data. There were some specific problems encountered during the 2005 cruises summarized below:
During HOT-172 the thermosalinograph system #1392 and remote temperature sensor #1496 were exchanged for sensors #2045 and #2078 with a more recent calibration early in the cruise after data acquisition had been started. However the conductivity sensor in the new thermosalinograph #2045 was found to be faulty and the original sensor #1392 was placed back into service. Data over this period were flagged as bad and not reported in the final data set.

Cruises aboard the R/V Kilo Moana during 2005 (HOT-169, 170, 173, 174, and 175) were affected by a small freshwater leak into the water jacket containing the thermosalinograph. Pumping freshwater into the pressure tank to renew the supply to the ships' living spaces during the cruise, forced water through a valve associated with the after-use rinsing and flushing of the thermosalinograph system. It was not until HOT-174 that regular sharp decreases in salinity followed by a slow return to ambient salinity values similar to a saw tooth pattern were first noticed. The problem was not traced to the gradual deterioration of the valve with changes in pressure of the freshwater system until December 2006. Typically the decreases in salinity were of an order of 0.02 psu.

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-167 through HOT-176 (Table 2.11).

Table 2.11: Noise Estimates for thermosalinograph data during 2005 cruises

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Salinity Noise (psu)</th>
<th>Temperature Noise (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>0.0035</td>
<td>0.0065</td>
</tr>
<tr>
<td>HOT-168</td>
<td>0.0022</td>
<td>0.0075</td>
</tr>
<tr>
<td>HOT-169</td>
<td>0.0011</td>
<td>0.0045</td>
</tr>
<tr>
<td>HOT-170</td>
<td>0.0017</td>
<td>0.0058</td>
</tr>
<tr>
<td>HOT-171</td>
<td>0.0018</td>
<td>0.0067</td>
</tr>
<tr>
<td>HOT-172</td>
<td>0.0022</td>
<td>0.0053</td>
</tr>
<tr>
<td>HOT-173</td>
<td>0.0012</td>
<td>0.0035</td>
</tr>
<tr>
<td>HOT-174</td>
<td>0.0024</td>
<td>0.0043</td>
</tr>
<tr>
<td>HOT-175</td>
<td>0.0013</td>
<td>0.0044</td>
</tr>
<tr>
<td>HOT-176</td>
<td>0.0016</td>
<td>0.0047</td>
</tr>
</tbody>
</table>

### 2.2.2.3 Conductivity Calibration

The thermosalinograph salinity was calibrated by comparing it to bottle salinity samples drawn from the plumbing near the thermosalinograph. Bottle salinity samples were analyzed as described in Section 2.1.3.
The bottle sampling areas aboard the R/V *Wecoma*, the R/V *Kilo Moana*, the R/V *Melville*, and the R/V *Ka'imikai-O-Kanaloa* was located immediately next to the thermostalinograph used to calculate salinity; therefore thermostalinograph 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 thermostalinograph conductivity separately for all the 2005 HOT cruises. The correction of the thermostalinograph conductivities was obtained from this fit. Salinity was calculated using these corrected conductivities, thermostalinograph temperatures, and the pressure of the pump. The mean values for the salinity bottle minus final calibrated thermostalinograph were less than +/- 4 x 10^-6 for all cruises (Table 2.12).

**Table 2.12: Bottle-Thermostalinograph salinity comparison during HOT 2005 cruises.**

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>1030</td>
<td>0.0026</td>
</tr>
<tr>
<td>HOT-168</td>
<td>1030</td>
<td>0.0013</td>
</tr>
<tr>
<td>HOT-169</td>
<td>3167</td>
<td>0.0019</td>
</tr>
<tr>
<td>HOT-170</td>
<td>3167</td>
<td>0.0021</td>
</tr>
<tr>
<td>HOT-171</td>
<td>0067</td>
<td>0.0011</td>
</tr>
<tr>
<td>HOT-172</td>
<td>1392</td>
<td>0.0037</td>
</tr>
<tr>
<td>HOT-173</td>
<td>3167</td>
<td>0.0021</td>
</tr>
<tr>
<td>HOT-174</td>
<td>3211</td>
<td>0.0023</td>
</tr>
<tr>
<td>HOT-175</td>
<td>3211</td>
<td>0.0016</td>
</tr>
<tr>
<td>HOT-176</td>
<td>2045</td>
<td>0.0030</td>
</tr>
</tbody>
</table>

### 2.2.2.4 Comparison with the CTD Data

The external temperature and the calibrated thermostalinograph salinity data collected during CTD casts were compared with the downcast CTD salinity from similar depth as the intake as an additional quality control. This procedure was conducted in the same manner as previously reported HOT cruises. The thermostalinograph data were averaged using data sampled one minute after the acquisition time of the CTD sample. Mean comparisons with the CTD were smaller than +/- 0.006 °C and +/- 0.003 PSU for all cruises (see Table 2.13). Note that the CTD-external temperatures are zero for cruises 169-171, and 173-175 because the external temperatures were offset to match the CTD temperatures to correct for the heating of the external temperatures on the R/V Kilo Moana (see Section 2.2.1).
Table 2.13: CTD - External Temperature and CTD – Thermosalinograph salinity comparison during HOT 2005 cruises.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>CTD-External Temperature (ºC)</th>
<th>Sensor #</th>
<th>CTD-Thermosalinograph Salinity</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-167</td>
<td>2490</td>
<td>-0.006</td>
<td>1030</td>
<td>-0.001</td>
</tr>
<tr>
<td>HOT-168</td>
<td>2490</td>
<td>-0.006</td>
<td>1030</td>
<td>0.000</td>
</tr>
<tr>
<td>HOT-169</td>
<td>0150</td>
<td>0.000*</td>
<td>3167</td>
<td>-0.000</td>
</tr>
<tr>
<td>HOT-170</td>
<td>0150</td>
<td>-0.000*</td>
<td>3167</td>
<td>-0.000</td>
</tr>
<tr>
<td>HOT-171</td>
<td>-</td>
<td>0.000*</td>
<td>0067</td>
<td>-0.000</td>
</tr>
<tr>
<td>HOT-172</td>
<td>2078</td>
<td>0.002</td>
<td>1392</td>
<td>-0.001</td>
</tr>
<tr>
<td>HOT-173</td>
<td>0150</td>
<td>0.000*</td>
<td>3167</td>
<td>-0.000</td>
</tr>
<tr>
<td>HOT-174</td>
<td>0169</td>
<td>-0.000*</td>
<td>3211</td>
<td>-0.001</td>
</tr>
<tr>
<td>HOT-175</td>
<td>0169</td>
<td>0.000*</td>
<td>3211</td>
<td>0.001</td>
</tr>
<tr>
<td>HOT-176</td>
<td>2078</td>
<td>-0.005</td>
<td>2045</td>
<td>-0.003</td>
</tr>
</tbody>
</table>

*after offset applied

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 Wecoma, R/V Ka’Imikai-O-Kanaloa, R/V Melville, and on the R/V Kilo Moana were also available.

Also available were hourly atmospheric pressure, air temperature, SST, and wind velocities from NDBC buoy #51001 (23.4°N, 162.3°W).

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 buoy data.

2.4 ADCP Measurements

Upper ocean currents were measured during HOT-172, and -176 cruises using the ADCP mounted on the R/V Ka’Imikai-O-Kanaloa (RD Instruments model VM-150). ADCP velocities were corrected for gyro compass errors as measured by the Ashtec 3DF GPS attitude sensor. Cruises HOT-167 and -168 used the ADCP mounted on the R/V Wecoma (RD Instruments
model OS-75). Cruise HOT-171 used the ADCP from the R/V Melville (RD Instruments model OS-38). Cruises HOT-169, -170, -173 through -175 used the ADCP on the R/V Kilo Moana (RD Instruments model OS-38). There were no significant data recording gaps. GPS navigation (differential or PCODE) was available throughout all cruises. Rough weather or seas on northward transits caused reduced returns on some of the cruises. These conditions resulted in velocity bias in the direction of ship's motion. Biased regions have been edited out, and will therefore appear as gaps in the plots. Gaps in the on-station data during some of the cruises are due to excursions to retrieve the primary productivity array and floating sediment traps.

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 2005.

2.5.1 Dissolved Oxygen

Dissolved oxygen samples were collected and analyzed using a computer-controlled potentiometric end-point titration procedure as described in Tupas et al. (1997). As in previous years we measured, using a calibrated digital thermistor, the temperature of the seawater sample at the time the iodine flask was filled. This was done to evaluate the magnitude of sample temperature error that affects the calculation of oxygen concentrations in units of µmol kg⁻¹. Figure 2.3 (upper panel) shows a plot of the difference between sample temperature and potential temperature computed from the in situ temperature measured at the time of bottle trip, versus pressure. Figure 2.3 (lower panel) shows a plot of the difference between oxygen concentrations calculated using the sample temperature and potential temperature versus pressure. The depth dependent variability in Δ oxygen is a result of: 1) bottle warming as the rosette is brought up through the water column 2) warm air entering the niskin bottle as samples are being taken and 3) evaporative cooling that occurs while on-deck as bottles are waiting to be sampled.

Precision of the Winkler titration method is presented in Table 2.14. The pooled annual mean CV of our oxygen analyses in 2005 was 0.18 %, which was calculated by averaging the mean CV of N-triplicate samples on each cruise. Oxygen concentrations measured over the 17 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 2.4 [upper panel]). These results indicate that analytical consistency has been maintained over the past 17 years of the HOT program.
Table 2.14: Precision of Winkler titration method during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>Dissolved O₂</th>
<th>Mean CV (%)</th>
<th>Mean SD (µmol kg⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>167</td>
<td></td>
<td>0.31</td>
<td>0.48</td>
<td>8</td>
</tr>
<tr>
<td>168</td>
<td></td>
<td>0.09</td>
<td>0.17</td>
<td>7</td>
</tr>
<tr>
<td>169</td>
<td></td>
<td>0.14</td>
<td>0.23</td>
<td>8</td>
</tr>
<tr>
<td>170</td>
<td></td>
<td>0.16</td>
<td>0.28</td>
<td>8</td>
</tr>
<tr>
<td>171</td>
<td></td>
<td>0.15</td>
<td>0.28</td>
<td>8</td>
</tr>
<tr>
<td>172</td>
<td></td>
<td>0.22</td>
<td>0.37</td>
<td>8</td>
</tr>
<tr>
<td>173</td>
<td></td>
<td>0.18</td>
<td>0.31</td>
<td>8</td>
</tr>
<tr>
<td>174</td>
<td></td>
<td>0.18</td>
<td>0.34</td>
<td>9</td>
</tr>
<tr>
<td>175</td>
<td></td>
<td>0.23</td>
<td>0.42</td>
<td>9</td>
</tr>
<tr>
<td>176</td>
<td></td>
<td>0.16</td>
<td>0.29</td>
<td>9</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>0.18</td>
<td>0.31</td>
<td>10</td>
</tr>
</tbody>
</table>

2.5.2 Dissolved Inorganic Carbon and Titration 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 2005 was 0.02 % (Table 2.15). It was calculated by averaging the mean CV of N-duplicate samples on each cruise. Total (titration) alkalinity (Talk) was determined using the modified Gran titration method as described in Tupas et al. (1997). The pooled annual CV of the alkalinity analyses during 2005 was 0.07 % (Table 2.15). The accuracy of DIC and alkalinity measurements was established with certified reference materials (CRMs) obtained from Andrew Dickson at Scripps Institution of Oceanography.
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.
Table 2.15: Precision of DIC and Total Alkalinity analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>DIC</th>
<th>Talk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µmol kg⁻¹)</td>
</tr>
<tr>
<td>167</td>
<td>0.01</td>
<td>0.25</td>
</tr>
<tr>
<td>168</td>
<td>0.01</td>
<td>0.14</td>
</tr>
<tr>
<td>169</td>
<td>0.02</td>
<td>0.32</td>
</tr>
<tr>
<td>170</td>
<td>0.02</td>
<td>0.38</td>
</tr>
<tr>
<td>171</td>
<td>0.03</td>
<td>0.68</td>
</tr>
<tr>
<td>172</td>
<td>0.02</td>
<td>0.47</td>
</tr>
<tr>
<td>173</td>
<td>0.03</td>
<td>0.59</td>
</tr>
<tr>
<td>174</td>
<td>0.02</td>
<td>0.36</td>
</tr>
<tr>
<td>175</td>
<td>0.01</td>
<td>0.13</td>
</tr>
<tr>
<td>176</td>
<td>0.01</td>
<td>0.21</td>
</tr>
<tr>
<td>Mean</td>
<td>0.02</td>
<td>0.35</td>
</tr>
</tbody>
</table>

2.5.3 Inorganic Nutrients

2.5.3.1 Standard Methods

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). Analyses were conducted on a four-channel Technicon Autoanalyzer II continuous flow system at the University of Hawaii Analytical Services Facility. The average precisions during 2005 from duplicate analyses are given in Table 2.16. Figures 2.4-2.5 show the mean and 95% confidence limits of nutrient concentrations measured at three potential density horizons for the 17 years of the program. In addition to standard automated nutrient analyses, specialized chemical methods are used to determine concentrations of nutrients that are normally below the detection limits of autoanalyzer methods.
Table 2.16: Precision of Dissolved inorganic nutrient analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>[Nitrate + Nitrite]</th>
<th>SRP</th>
<th>Silicate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µM)</td>
<td>N</td>
</tr>
<tr>
<td>167</td>
<td>0.19</td>
<td>0.057</td>
<td>7</td>
</tr>
<tr>
<td>168</td>
<td>0.19</td>
<td>0.054</td>
<td>7</td>
</tr>
<tr>
<td>169</td>
<td>1.84</td>
<td>0.677</td>
<td>6</td>
</tr>
<tr>
<td>170</td>
<td>0.18</td>
<td>0.052</td>
<td>7</td>
</tr>
<tr>
<td>171</td>
<td>1.59</td>
<td>0.037</td>
<td>7</td>
</tr>
<tr>
<td>172</td>
<td>1.31</td>
<td>0.059</td>
<td>7</td>
</tr>
<tr>
<td>173</td>
<td>1.94</td>
<td>0.273</td>
<td>7</td>
</tr>
<tr>
<td>174</td>
<td>2.02</td>
<td>0.071</td>
<td>7</td>
</tr>
<tr>
<td>175</td>
<td>0.17</td>
<td>0.048</td>
<td>7</td>
</tr>
<tr>
<td>176</td>
<td>0.31</td>
<td>0.052</td>
<td>7</td>
</tr>
<tr>
<td>Mean</td>
<td>0.97</td>
<td>0.138</td>
<td>10</td>
</tr>
</tbody>
</table>

Between 2001 and 2004, the HOT nutrient program underwent substantial changes, including switching analysts twice, eventually establishing an analytical nutrient laboratory centered around a six-channel Bran Luebbe Autoanalyzer III. In an effort to continue to provide high-quality nutrient data to the scientific community during this transition period, we made the decision to ship nutrient samples to Oregon State University for nutrient analyses. The decision to send samples to OSU was reached after a blind nutrient analyses comparison was conducted among several oceanographic analytical laboratories (including UW, SIO, OSU and UH). Each laboratory received triplicate nutrient samples collected at 4 depths (750, 1200, 2200 and 4200 m) on HOT-163. Using our historical nutrient data as reference, we compared analyses of NO$_2$+NO$_3$, and PO$_4$ by these laboratories; analyses conducted by OSU were within our historical nutrient concentration climatology. As a result, samples from $>200$ m depth from HOT 127-166 (Jun 2001 to December 2004) were shipped to OSU for analyses.

The OSU nutrient facility uses an AutoAnalyzer II manifold with 5 cm flow cell for PO$_4$ analyses, and an Alpkem RFA 300 system for analyses of NO$_2$+NO$_3$. 
Figure 2.4: 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 2.5: 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] Silicate.
2.5.3.2 High Sensitivity Methods

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).

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.

2.5.4 Dissolved Organic Matter

2.5.4.1 Dissolved Organic Carbon

Dissolved organic carbon (DOC) was determined by the high temperature catalytic oxidation method using a Shimadzu 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. Beginning in 1997, certified TOC reference materials were obtained from J. Sharp (University of Delaware) and D. Hansell (University of Miami) and run each time TOC concentrations were analyzed. UV-oxidation distilled water is used to determine the instrument blank. The average precisions during 2005 from duplicate TOC analyses are given in Table 2.17.

Table 2.17: Precision of Dissolved organic carbon analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>DOC</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µM)</td>
</tr>
<tr>
<td>167</td>
<td>2.1</td>
<td>0.76</td>
</tr>
<tr>
<td>168</td>
<td>1.5</td>
<td>0.56</td>
</tr>
<tr>
<td>169</td>
<td>4.5</td>
<td>1.76</td>
</tr>
<tr>
<td>170</td>
<td>2.5</td>
<td>0.98</td>
</tr>
<tr>
<td>171</td>
<td>1.3</td>
<td>0.53</td>
</tr>
<tr>
<td>172</td>
<td>1.5</td>
<td>0.56</td>
</tr>
<tr>
<td>173</td>
<td>5.8</td>
<td>2.39</td>
</tr>
<tr>
<td>174</td>
<td>2.0</td>
<td>0.74</td>
</tr>
<tr>
<td>175</td>
<td>4.1</td>
<td>1.51</td>
</tr>
<tr>
<td>176</td>
<td>1.5</td>
<td>0.53</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td><strong>2.7</strong></td>
<td><strong>1.03</strong></td>
</tr>
</tbody>
</table>
2.5.4.2 Dissolved Organic Nitrogen and Phosphorus

Dissolved organic nitrogen (DON) was calculated as the difference between total dissolved fixed nitrogen (TDN) and [nitrate+nitrite] concentrations. DON by this definition also includes ammonium, however, ammonium concentrations in these waters are below the detection limit of standard nutrient analyses (~50 nM). Dissolved organic phosphorus (DOP) was calculated as the difference between total dissolved phosphorus (TDP) and SRP concentrations. DOP, by this definition includes inorganic polyphosphates. TDN and TDP were determined by the UV oxidation method as described in Tupas et al. (1997). The average precisions during 2000 from duplicate analyses are presented in Table 2.18.

Table 2.18: Precision of Dissolved organic nitrogen and phosphorus analyses during 2000

<table>
<thead>
<tr>
<th>HOT</th>
<th>DON</th>
<th>DOP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µM)</td>
</tr>
<tr>
<td></td>
<td>Mean N</td>
<td></td>
</tr>
<tr>
<td>111</td>
<td>2.4</td>
<td>0.03</td>
</tr>
<tr>
<td>112</td>
<td>4.4</td>
<td>0.10</td>
</tr>
<tr>
<td>113</td>
<td>3.4</td>
<td>0.16</td>
</tr>
<tr>
<td>114</td>
<td>6.7</td>
<td>0.20</td>
</tr>
<tr>
<td>115</td>
<td>8.1</td>
<td>0.33</td>
</tr>
<tr>
<td>116</td>
<td>9.1</td>
<td>0.27</td>
</tr>
<tr>
<td>117</td>
<td>10.1</td>
<td>0.34</td>
</tr>
<tr>
<td>118</td>
<td>6.1</td>
<td>0.58</td>
</tr>
<tr>
<td>119</td>
<td>4.8</td>
<td>0.17</td>
</tr>
<tr>
<td>120</td>
<td>3.5</td>
<td>0.11</td>
</tr>
<tr>
<td>121</td>
<td>9.7</td>
<td>0.55</td>
</tr>
<tr>
<td>Mean</td>
<td>6.2</td>
<td>0.26</td>
</tr>
</tbody>
</table>

2.5.5 Particulate Bioelements

2.5.5.1 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 25 mm GF/F glass fiber filters. They were analyzed using a Carla Erba NC 2500 Elemental Analyzer with a Finnigan MAT ConFlo II coupler and a Finnigan MAT DeltaS mass spectrometer. The average precisions during 2005 determined from duplicate analyses are presented in Table 2.19.
Table 2.19: Precision of Particulate carbon and nitrogen analyses during 2005

<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>167</td>
<td>8.5</td>
<td>1.160</td>
</tr>
<tr>
<td>168</td>
<td>3.4</td>
<td>0.643</td>
</tr>
<tr>
<td>169</td>
<td>3.9</td>
<td>0.820</td>
</tr>
<tr>
<td>170</td>
<td>16.4</td>
<td>4.324</td>
</tr>
<tr>
<td>171</td>
<td>3.6</td>
<td>0.894</td>
</tr>
<tr>
<td>172</td>
<td>12.1</td>
<td>2.517</td>
</tr>
<tr>
<td>173</td>
<td>5.2</td>
<td>1.602</td>
</tr>
<tr>
<td>174</td>
<td>14.1</td>
<td>2.775</td>
</tr>
<tr>
<td>175</td>
<td>2.7</td>
<td>0.601</td>
</tr>
<tr>
<td>176</td>
<td>12.4</td>
<td>3.079</td>
</tr>
<tr>
<td>Mean</td>
<td>8.2</td>
<td>1.842</td>
</tr>
</tbody>
</table>

2.5.5.2 Particulate Phosphorus

Samples for elemental analyses of Particulate phosphorus were prefiltered through 202 µm Nitex mesh to remove large zooplankton and collected onto combusted, acid washed 25 mm GF/F glass fiber filters. 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 precisions during 2005 determined from duplicate analyses are presented in Table 2.20.

Table 2.20: Precision of Particulate phosphorus analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
</tr>
<tr>
<td>167</td>
<td>25.1</td>
</tr>
<tr>
<td>168</td>
<td>27.0</td>
</tr>
<tr>
<td>169</td>
<td>0.0</td>
</tr>
<tr>
<td>170</td>
<td>10.5</td>
</tr>
<tr>
<td>171</td>
<td>37.9</td>
</tr>
<tr>
<td>172</td>
<td>22.4</td>
</tr>
<tr>
<td>173</td>
<td>20.0</td>
</tr>
<tr>
<td>174</td>
<td>8.8</td>
</tr>
<tr>
<td>175</td>
<td>22.2</td>
</tr>
<tr>
<td>176</td>
<td>12.8</td>
</tr>
<tr>
<td>Mean</td>
<td>18.7</td>
</tr>
</tbody>
</table>
2.5.5.3 Particulate Biogenic Silica

Samples for elemental analyses of Particulate biogenic silica 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 precisions during 2005 determined from duplicate analyses are presented in Table 2.21.

Table 2.21: Precision of Particulate biogenic silica analyses during 2005

<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>167</td>
<td>5.5</td>
<td>0.590</td>
<td>2</td>
</tr>
<tr>
<td>168</td>
<td>17.6</td>
<td>3.122</td>
<td>2</td>
</tr>
<tr>
<td>169</td>
<td>20.4</td>
<td>1.966</td>
<td>2</td>
</tr>
<tr>
<td>170</td>
<td>10.5</td>
<td>4.080</td>
<td>2</td>
</tr>
<tr>
<td>171</td>
<td>9.8</td>
<td>3.270</td>
<td>2</td>
</tr>
<tr>
<td>172</td>
<td>22.3</td>
<td>2.899</td>
<td>2</td>
</tr>
<tr>
<td>173</td>
<td>22.2</td>
<td>19.562</td>
<td>2</td>
</tr>
<tr>
<td>174</td>
<td>18.1</td>
<td>2.160</td>
<td>2</td>
</tr>
<tr>
<td>175</td>
<td>7.0</td>
<td>0.976</td>
<td>2</td>
</tr>
<tr>
<td>176</td>
<td>12.1</td>
<td>1.230</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>14.5</td>
<td>3.986</td>
<td>10</td>
</tr>
</tbody>
</table>

2.5.6 Pigments

2.5.6.1 Standard Fluorometric Method

Samples for chlorophyll a (chl a) and pheopigments were collected onto 25 mm GF/F glass fiber filters 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 2005 determined from triplicate analyses are presented in Table 2.22.

2.5.6.2 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 2005 are presented in Table 2.23. Figure 2.6 shows the relationship between chlorophyll a measured by fluorometry and chlorophyll a measured by HPLC during 2005.
Table 2.22: Precision of Fluorometric Chlorophyll $a$ and Pheopigment analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>Chlorophyll $a$</th>
<th></th>
<th></th>
<th>Pheopigments</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD ($\mu g , l^{-1}$)</td>
<td>N</td>
<td>Mean CV (%)</td>
<td>Mean SD ($\mu g , l^{-1}$)</td>
<td>N</td>
</tr>
<tr>
<td>167</td>
<td>13.9</td>
<td>0.006</td>
<td>6</td>
<td>9.0</td>
<td>0.010</td>
<td>6</td>
</tr>
<tr>
<td>168</td>
<td>30.1</td>
<td>0.016</td>
<td>6</td>
<td>29.7</td>
<td>0.027</td>
<td>6</td>
</tr>
<tr>
<td>169</td>
<td>3.2</td>
<td>0.004</td>
<td>6</td>
<td>2.5</td>
<td>0.006</td>
<td>6</td>
</tr>
<tr>
<td>170</td>
<td>11.0</td>
<td>0.005</td>
<td>6</td>
<td>8.5</td>
<td>0.013</td>
<td>6</td>
</tr>
<tr>
<td>171</td>
<td>7.1</td>
<td>0.007</td>
<td>6</td>
<td>7.7</td>
<td>0.013</td>
<td>6</td>
</tr>
<tr>
<td>172</td>
<td>6.2</td>
<td>0.007</td>
<td>6</td>
<td>9.0</td>
<td>0.013</td>
<td>6</td>
</tr>
<tr>
<td>173</td>
<td>8.1</td>
<td>0.006</td>
<td>6</td>
<td>6.5</td>
<td>0.006</td>
<td>6</td>
</tr>
<tr>
<td>174</td>
<td>8.0</td>
<td>0.008</td>
<td>6</td>
<td>9.6</td>
<td>0.014</td>
<td>6</td>
</tr>
<tr>
<td>175</td>
<td>6.1</td>
<td>0.005</td>
<td>6</td>
<td>4.1</td>
<td>0.008</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>10.2</td>
<td>0.007</td>
<td>10</td>
<td>9.2</td>
<td>0.012</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2.23: 2005 HPLC Pigment analysis Response factors and Retention times

<table>
<thead>
<tr>
<th>Pigment</th>
<th>RF$^a$</th>
<th>RT$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chlorophyll c &amp; Mg 3,8D$^c$</td>
<td>0.323</td>
<td>0.354</td>
</tr>
<tr>
<td>Peridinin</td>
<td>0.527</td>
<td>0.382</td>
</tr>
<tr>
<td>19'-Butanoyloxyfucoxanthin</td>
<td>0.367</td>
<td>0.385</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>0.368</td>
<td>0.415</td>
</tr>
<tr>
<td>19'-Hexanoyloxyfucoxanthin</td>
<td>0.365</td>
<td>0.455</td>
</tr>
<tr>
<td>Prasinoxanthin</td>
<td>0.402</td>
<td>0.507</td>
</tr>
<tr>
<td>Violaxanthin</td>
<td>0.268</td>
<td>0.536</td>
</tr>
<tr>
<td>Diadinoxanthin</td>
<td>0.275</td>
<td>0.608</td>
</tr>
<tr>
<td>Alloxanthin</td>
<td>0.279</td>
<td>0.660</td>
</tr>
<tr>
<td>Lutein</td>
<td>0.285</td>
<td>0.752</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>0.304</td>
<td>0.769</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll b</td>
<td>0.961</td>
<td>0.935</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll a</td>
<td>0.719</td>
<td>1.000</td>
</tr>
<tr>
<td>Divinyl Chlorophyll a</td>
<td>0.498</td>
<td>1.000</td>
</tr>
<tr>
<td>$\alpha$-Carotene</td>
<td>0.282</td>
<td>1.171</td>
</tr>
<tr>
<td>$\beta$-Carotene</td>
<td>0.304</td>
<td>1.178</td>
</tr>
</tbody>
</table>

$^a$RF - Response Factor (ng l$^{-1}$ pigment per unit absorbance peak area at 436 nm).

$^b$RT - Retention Time (minutes, relative to chlorophyll a).

$^c$Chlorophyll c = (c$_1$ + c$_2$ + c$_3$), Mg 3,8D = Mg 3,8 divinyl pheoporphyrin a$_5$ monomethyl ester.
Figure 2.6: Chlorophyll a measured by fluorometry (Chla F) versus chlorophyll a measured by HPLC (Chla HPLC) for all data collected in 2005. 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.
2.5.6.3 Chlorophyll $a$, $b$, $c$

In mid-2000 we started measuring chlorophyll $a$, $b$, & $c$ on a Turner Designs TD-700. Samples were filtered onto 25 mm GF/F glass fiber filters and put into 100% acetone similar to the standard fluorometric method (Section 2.5.6.1). Samples were analyzed using the wavelength filters shown in Table 2.24. The average precisions during 2005 determined from triplicate analyses are presented in Table 2.25. Figure 2.7 shows the relationship between chlorophyll $a$ measured using the TD-700 & chlorophyll $a$ measured using the 10-AU as well as chlorophyll $a$, $b$ & $c$ measured by HPLC during 2005.

Table 2.24: Wavelength filters used for TD-700 Chlorophyll analyses

<table>
<thead>
<tr>
<th>Chlorophyll</th>
<th>Ex</th>
<th>Em</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a$</td>
<td>436</td>
<td>680</td>
</tr>
<tr>
<td>$b$</td>
<td>480</td>
<td>650</td>
</tr>
<tr>
<td>$c$</td>
<td>450</td>
<td>630</td>
</tr>
</tbody>
</table>

Table 2.25: Precision of TD-700 Chlorophyll analyses during 2005

<table>
<thead>
<tr>
<th>HOT</th>
<th>Chlorophyll $a$</th>
<th>Chlorophyll $b$</th>
<th>Chlorophyll $c$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µg l$^{-1}$)</td>
<td>N</td>
</tr>
<tr>
<td>169</td>
<td>1.8</td>
<td>0.003</td>
<td>6</td>
</tr>
<tr>
<td>170</td>
<td>1.7</td>
<td>0.003</td>
<td>6</td>
</tr>
<tr>
<td>171</td>
<td>2.1</td>
<td>0.003</td>
<td>6</td>
</tr>
<tr>
<td>172</td>
<td>1.7</td>
<td>0.004</td>
<td>6</td>
</tr>
<tr>
<td>173</td>
<td>1.7</td>
<td>0.003</td>
<td>6</td>
</tr>
<tr>
<td>174</td>
<td>2.6</td>
<td>0.004</td>
<td>6</td>
</tr>
<tr>
<td>175</td>
<td>1.3</td>
<td>0.002</td>
<td>6</td>
</tr>
<tr>
<td>176</td>
<td>3.7</td>
<td>0.004</td>
<td>6</td>
</tr>
<tr>
<td>Mean</td>
<td>2.1</td>
<td>0.003</td>
<td>8</td>
</tr>
</tbody>
</table>

2.5.6.4 Underway Surface Chloropigment

Continuous in vivo chloropigment (fluorescence) from surface seawater was measured using a Turner Designs Model 10-AU fluorometer installed on the ship’s seawater intake system. The underway measurements were calibrated by taking discrete samples from the outflow of the fluorometer and extracting the pigments according to the standard fluorometric method (Section 2.5.6.1).
Figure 2.7: Chlorophyll measured using the TD-700 versus chlorophyll measured using the 10-AU and by HPLC for all data collected in 2005. 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 each figure.
2.5.6.5 Phycoerythrin

Unlike the HPLC pigments which are oil soluble, phycoerythrin is a water soluble pigment which can be used as a marker for cyanobacteria such as Trichodesmium spp. Samples were size fractionated through 10µm & 5µm nylon membrane filters, 1L of the filtrate collected, then poured through a 0.4µm poly-carbonate filter. Samples were analyzed using a Turner Designs TD-700 with 544 nm (Ex) & 577 nm (Em) wavelength filters, and the fluorescence obtained. Phycoerythrin was then calculated via the formula:

\[
\text{PE} = \frac{\text{fluor} - B}{M}
\]

where M & B are the slope and intercept respectively of the regression curve obtained by using our pure phycoerythrin stock.

2.5.7 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 47 mm GF/F glass fiber filters to collect particulate material and the filters placed in boiling Tris-buffer for ATP extraction. ATP concentrations were determined using the firefly bioluminescence technique described by Karl and Holm-Hansen (1978).

The average precisions of Particulate ATP determinations during 2005 determined from triplicate analyses are presented in Table 2.26.

<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>167</td>
<td>17.0</td>
<td>1.943</td>
<td>9</td>
</tr>
<tr>
<td>168</td>
<td>13.0</td>
<td>2.687</td>
<td>9</td>
</tr>
<tr>
<td>169</td>
<td>9.6</td>
<td>2.539</td>
<td>9</td>
</tr>
<tr>
<td>170</td>
<td>11.0</td>
<td>2.097</td>
<td>9</td>
</tr>
<tr>
<td>171</td>
<td>20.4</td>
<td>4.097</td>
<td>9</td>
</tr>
<tr>
<td>172</td>
<td>15.9</td>
<td>2.289</td>
<td>9</td>
</tr>
<tr>
<td>173</td>
<td>17.0</td>
<td>2.570</td>
<td>9</td>
</tr>
<tr>
<td>174</td>
<td>17.2</td>
<td>1.851</td>
<td>9</td>
</tr>
<tr>
<td>175</td>
<td>9.9</td>
<td>2.545</td>
<td>9</td>
</tr>
<tr>
<td>176</td>
<td>18.0</td>
<td>2.523</td>
<td>8</td>
</tr>
<tr>
<td>Mean</td>
<td>14.9</td>
<td>2.514</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2.26: Precision of Particulate ATP analyses during 2005
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. Some incubations during 1988-1990 were carried out *in situ*, and some on deck under simulated *in situ* light and temperature conditions. 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 2.5.5 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

Vertical profiles of upwelling radiance and downwelling irradiance were made using a Biospherical PRR-600 Profiling Reflectance Radiometer. Surface irradiance was collected using a sister instrument (PRR-610). These instruments measures downwelling irradiance (Ed) and upwelling radiance (Lu) as well as surface irradiance (Es) from a deck unit on 7 wavelength channels (Table 2.27). The radiance channels comply with the SeaWIFS satellite optical parameters. The instrument is lowered by hand and depending on the subsurface currents, is deployed to a depth between 125 and 175 meters.
Table 2.2: PRR-600 and PRR-610 Wavelengths

<table>
<thead>
<tr>
<th>Channel</th>
<th>Downwelling (Ed)</th>
<th>Upwelling (Lu)</th>
<th>Surface (Es)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>412</td>
<td>412</td>
<td>412</td>
</tr>
<tr>
<td>2</td>
<td>443</td>
<td>443</td>
<td>443</td>
</tr>
<tr>
<td>3</td>
<td>490</td>
<td>490</td>
<td>490</td>
</tr>
<tr>
<td>4</td>
<td>510</td>
<td>510</td>
<td>510</td>
</tr>
<tr>
<td>5</td>
<td>555</td>
<td>555</td>
<td>555</td>
</tr>
<tr>
<td>6</td>
<td>665</td>
<td>665</td>
<td>665</td>
</tr>
<tr>
<td>7</td>
<td>PAR</td>
<td>683</td>
<td>PAR</td>
</tr>
</tbody>
</table>

2.7.3 Tethered Spectral Radiometer Buoy (TSRB)

The TSRB was used to make continuous measurements of downwelling irradiance just above the sea surface, upwelling radiance just below the sea surface, and sea surface temperature at the sea surface. The instrument measures downwelling irradiance at 489nm and upwelling radiance at 410, 444, 489, 511, 553, 668 and 684nm. All wavelengths except the 684nm waveband have bandpasses of approximately 20nm. The 684nm waveband has a bandpass of 10nm. The sampling frequency is 1 Hz.

During HOT-151 (August 2003), the TSRB got tangled in the ship’s aft propeller. Due to marginal sea conditions, the captain deemed it unsafe to send a diver to untangle the buoy. The wire was cut in the hope that the buoy would untangle itself and float to the surface. It did not. At present, we have TSRB data from HOT-89 through HOT-150 (January 1998 – July 2003).

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. 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-9 was part of an instrument package that also included a Sea-Bird CTD, WET Labs WetStar fluorometer and a Chelsea Fast Repetition Rate Fluorometer (FRRF). The instrument was oriented horizontally and lowered at a more-or-less constant speed of 10 m min$^{-1}$ to a bottom depth of approximately 250 m (justification given in Section 2.7.5). At least 2 back-to-back profiles were normally taken, one using a 0.2 µm cartridge filter and one without. This allowed the spectral absorption and attenuation coefficient of both the total & dissolved matter to be determined. The particulate absorption and attenuation components were derived by subtracting the dissolved from the total component. The scattering of particles was estimated by subtracting the absorption from the attenuation particle spectrum.
2.7.5 Fast Repetition Rate Fluorometry (FRRF)

Day and night time FRRF profiles were made using a Chelsea FAST\textsuperscript{tracka} Dynamic Photosynthetic Fluorometer. The FRRF was part of an instrument package that also included a Sea-Bird CTD, WET Labs WETStar fluorometer and a WET Labs AC-9. The instrument was oriented horizontally and lowered at a more-or-less constant speed of 10 m min\textsuperscript{-1} to a bottom depth of approximately 250 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 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\textsuperscript{-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.

2.8 Microbial Community Structure

Analysis of microbial numbers was made using an EPICS 753 flow cytometer (Coulter Electronics Corporation, Hialeah, FL, USA) which has been upgraded with a Cicero Data Acquisition System (Cytomation Inc., Boulder, Colorado). Prior to analysis by flow cytometry, samples were prepared using standard protocols (Monger & Landry 1993; Campbell et al., 1994). Enumeration efficiency was tracked using fluorescent beads. Cyanobacteria of the genera \textit{Prochlorococcus} and \textit{Synechococcus} were separately enumerated, as well as non-pigmented bacteria/archaea and pigmented eukaryotes.

2.9 Zooplankton Community Structure

2.9.1 Mesozooplankton Collection

Samples for the quantification of mesozooplankton were collected using a 1 m\textsuperscript{2} plankton net with a 202 \( \mu \)m Nitex mesh. The net is towed obliquely at a speed of 1.0-1.5 knots while deploying and retrieving the tow line at a constant speed (about 20 meters min\textsuperscript{-1}; total line out = 200 meters; 20 minute tow duration; average depth of tow \( \approx \) 175 meters). Three midnight (between 2200-0200 local time) and three mid-day (between 1000-1400 local time) tows are conducted on each cruise. This sampling scheme allows maximal collection of vertical migrants during the night and minimal collection of vertical migrants during the day.

2.9.2 Sample Processing

Immediately after the net tows, contents of the collecting buckets (cod ends) are divided using a Folsom splitter. One-half of each tow is preserved in 4\% buffered formaldehyde, with 2 mg l\textsuperscript{-1} strontium sulfate added to prevent acantharians from dissolving. Approximately one-fourth of each tow, depending on sample density, is further size-fractionated through nested screens of 5, 2, 1, 0.5 and 0.2 mm Nitex mesh. Each size fraction is filtered onto a preweighed
0.2 μm Nitex filter, rinsed with isotonic ammonium formate to remove salts, sucked dry under low vacuum, and flash frozen in liquid nitrogen. In the lab, frozen samples are defrosted at room temperature and weighed wet (moist) on an analytical balance. After a wet weight is obtained random subsamples of the zooplankton mass are removed and set aside for enumeration, and the remaining sample is dried at 60 °C. Dry samples are reweighed to obtain a total sample dry weight [total sample dry weight = measured dry weight/fraction of total wet weight dried]. The dry samples are analyzed for carbon and nitrogen.
3.0 CRUISE SUMMARIES

The cruise summaries presented here give an overview of the activities conducted during the 2005 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-167

Chief Scientist: D. SADLER
R/V Wecoma
31 January – 4 February, 2005

All planned operations were completed. Fourteen 1000 m and two 4800 m CTD casts were obtained at Station ALOHA. A 1000 m cast was obtained at Station Kahe. Two 200 m casts were completed near the buoys. Also, three PRR casts were performed: one at Station Kahe and two at Station ALOHA. C. Hannides successfully completed six plankton net tows. The AC9/FRRf was deployed three times at Station ALOHA. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermostalinograph and the ship's anemometer. Weather during the cruise was mostly overcast with trade winds and occasional light rain. This was interrupted by some weather and wind out to the west on February 1 and 2. We returned to Snug Harbor on February 4 at 0800. A complete off-load took place immediately.

3.2 HOT-168

Chief Scientist: D. SADLER
R/V Wecoma
3-7 March 2005

All planned operations were completed. Thirteen 1000 m, one 4800 m and one 100 m CTD casts were obtained at Station ALOHA. A 1000 m cast was obtained at Station Kahe. Also, three PRR casts were performed at Station ALOHA. C. Sheridan successfully completed six plankton net tows. The AC9/FRRf was deployed four times at Station ALOHA. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermostalinograph and the ship's anemometer. Weather during the cruise was mostly overcast with trade winds and occasional light rain. This was interrupted by some weather and wind out to the west on March 4 and 5. We returned to Snug Harbor on March 7 at 0800. A complete off-load took place immediately. The bottom moored sediment traps were recovered.
3.3 HOT-169

Chief Scientist: T. GREGORY
R/V Kilo Moana
16-20 May 2005

All objectives for HOT-169 were successfully completed. Thirteen 1000 m casts, two 4740 m casts, and two 200 m casts were conducted at ALOHA; one 1000 m cast at Kahe, and one 250 m cast at Station 50. The 200 m CTD cast planned for Station 50 at the end of the cruise was moved to the beginning due to a faster than expected fueling operation at Pearl Harbor. M. Simmons successfully completed seven plankton net tows. The PRR and AC9/FRRf were deployed as planned. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermostalinograph and the ship's anemometer. Weather during the cruise was partly cloudy with 10-20 kt. trade winds from the northwest. We returned to Snug Harbor on May 20 at 1030. A complete off-load took place immediately.

3.4 HOT-170

Chief Scientist: F. SANTIAGO-MANDUJANO
R/V Kilo Moana
13-17 June 2005

Operations during most of the cruise were conducted as planned, with some changes in the schedule during the second day of the cruise. One 1000-m CTD cast within the 36-hr burst period had to be eliminated due to time constrains. One 1000-m CTD cast was conducted at Kahe station. Eleven 1000-m CTD casts, two deep casts (~4740 m), and two 200-m casts were conducted at Station ALOHA. Two 200-m CTD casts were conducted near the MOSEAN mooring (Station 51), and near the ORS mooring (Station 50) respectively. One near-bottom cast (~2400 m) was conducted at station Kaena (Station 6).

The array of floating sediment traps, the primary productivity incubation array, and the gas array were deployed and recovered without incidents. All arrays drifted southwest. C. Hannides completed successfully 8 plankton net tows. C. Mahaffey conducted one net tow. The PRR and AC9/FRRf were deployed as planned. The Automated Trace-Element Sampler was successfully used to collect one trace metal sample. The ADCP ran without interruption throughout the cruise, as well as the thermostalinograph, and the ship's two anemometers.

R. Rember tested successfully his bottle samplers by attaching them to the rosette frame during various CTD casts. His modules were independent and did not interfere with our regular operations. D. Hebel collected his samples and conducted his experiments as planned.

Winds were easterlies at 15-22 kt during the cruise. A strong southwestward current was present during the cruise as indicated by the drift of the floating arrays deployed during the cruise. We arrived back at Snug Harbor on June 17 at 0800. Full off-load took place immediately.
3.5 HOT-171

Chief Scientist: T. GREGORY  
R/V Melville  
15-19 July 2005

Most objectives for HOT 171 were successfully completed. We were unable to complete any PRR casts due to a problem with the communication cable. The CTD cast schedule at Station ALOHA had to be rearranged due to a problem with the pressure sensor on the primary CTD and the need to deploy the gas array in a timely fashion. All CTD casts planned for Station ALOHA were conducted as planned albeit in a different order except for the second deep cast which was cancelled. We did not do a cast at Station Kaena.

All free-floating arrays were deployed and recovered without incident. C. Hannides successfully completed six plankton net tows. Weather conditions were favorable throughout the cruise. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph and the ship's anemometer. We arrived back at Snug Harbor on July 19 at around 1030. A full off-load took place immediately.

3.6 HOT-172

Chief Scientist: T. GREGORY  
R/V Ka'imikai-o-Kanaloa  
12-16 August 2005

All objectives for HOT 172 were successfully completed. We experience a problem with the CTD computer which caused the delay of the 36 hour period and cancellation of one cast. All sampling objectives and the 36 hour period were completed nonetheless. In addition to core HOT objectives, we occupied three stations in the vicinity of Station ALOHA in order to characterize a phytoplankton bloom that was in the area.

All free-floating arrays were deployed and recovered without incident. C. Hannides successfully completed six plankton net tows. Weather conditions were favorable throughout the cruise. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph and the ship's anemometer. We arrived back at Snug Harbor on August 16 at around 800. A full off-load took place immediately.
3.7 HOT-173

Chief Scientist: F. SANTIAGO-MANDUJANO
R/V Kilo Moana
8-12 September 2005

Operations during most of the cruise were conducted as planned, with some changes in the schedule during the second day of the cruise. One 1000-m CTD cast within the 36-hr burst period had to be postponed due to time constraints. One near-bottom CTD cast (~1475 m) was conducted at Kahe station. Eleven 1000-m CTD casts, two deep casts (~4740 m), and four 200-m casts were conducted at Station ALOHA. Two 200-m CTD casts were conducted near the MOSEAN mooring (Station 51), and near the ORS mooring (Station 50) respectively. One near-bottom cast (~2400 m) was conducted at station Kaena (Station 6).

The array of floating sediment traps, the primary productivity incubation array, and the gas array were deployed and recovered without incidents. All arrays drifted northwest. The bottom-moored sediment trap was recovered without incidents. C. Mahaffey conducted six net tows. The PRR and AC9/FRRf were deployed as planned. The Automated Trace-Element Sampler was successfully used to collect one trace metal sample. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph, and the ship's two anemometers. C. Bobe collected her samples and conducted her experiments as planned.

Winds were easterlies at 15-20 kt during the cruise. Rain was intermittent during the cruise. We arrived back at Snug Harbor on September 12 at 0730. Only scientific personnel and some of the samples were unloaded, as the ship had an early appointment for fueling. Full off-load took place September 13.

3.8 HOT-174

Chief Scientist: T. GREGORY
R/V Kilo Moana
6-11 October 2005

All objectives for HOT 174 were successfully completed. Fifteen 1000 m, two 4800 m three 200 m and one 700 m CTD casts were obtained at Station ALOHA. One 1000 m cast was obtained at Station Kahe, one 500 m and one 200 m CTD cast was performed near the MOSEAN mooring, and one 2500 m cast was performed at Station Kaena. During the second deep cast, a commercial fishing longline got wrapped around the CTD wire. We successfully recovered the package and freed the longline intact however this complication delayed recovery of the CTD.

Three PRR casts and five AC9/FRRf casts were performed at Station ALOHA. The array of floating sediment traps, the primary productivity incubation array, and the gas array were deployed and recovered without incidents. All arrays drifted southwest. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph and the ship's anemometer. We returned to Snug Harbor on October 11 at 0800. A complete off-load took place immediately.
Operations during the cruise were interrupted on the second day due to the loss of the CTD/Rosette package. The CTD cable broke at 100 m during the first cast of the 36-hr burst period, and the CTD/rossette package including the Satlantic ISUS Nitrate sensor sank to the bottom. The incident happened at 12:37, November 11 when the CTD was being brought back to the surface. The cable broke near the crane's sheave, at the passage of a wave. Coordinates 22 44.997'N, 157 59.995'W. Operations continued after cutting about 540 m of wire, and using the OTG (STAG) rosette, bottles, CTD, sensors, and spare sensors from the PO group.

One 1000-m CTD cast was conducted at Kahe station. Twelve 1000-m CTD casts, two deep casts, (~4740 m, and 4000 m), four 200-m casts and one 100-m cast were conducted at Station ALOHA. One 1000-m CTD cast was conducted near the MOSEAN mooring (Station 51), and one 200-m cast near the WHOTS mooring (Station 50). One 2000-m cast was conducted at station Kaena (Station 6).

The array of floating sediment traps, and the primary productivity incubation array were deployed and recovered without incidents. The arrays drifted northwest. C. Stump retrieved his Glider. P. Lethaby fixed the anemometer on the WHOTS buoy. M. Landry and C. Mahaffey conducted successfully their respective net tows. Landry's old style net ripped at the surface upon recovery during the second tow of the cruise and was not used anymore. One of the tows was compromised because a half burnt cigarette, probably discharged from the ship was caught in the net. The PRR and AC9/FRRf were deployed as needed. The Automated Trace-Element Sampler was successfully used to collect one trace metal sample. The ADCP ran without interruption throughout the cruise, as well as the thermosalinograph, and the ship's two anemometers.

Winds were easterlies at about 15 kt during the cruise, decreasing to 10 kt and becoming southerlies by the end of the cruise. We arrived back at Snug Harbor on November 14 at 0730. Only scientific personnel and some of the samples were unloaded, as the ship departed at 1000 for a three day cruise to try to recover the CTD, and to conduct other experiments. Full off-load took place November 17.
Operations during the cruise were conducted as planned. One 1000-m CTD cast was conducted at Kahe station. Twelve 1000-m CTD casts, two 200-m, and two deep casts (~4740 m) were conducted at Station ALOHA. Two 200-m CTD casts were conducted near the WHOTS mooring (Sta. 50), and near the MOSEAN mooring (Sta. 51) respectively.

The array of floating sediment traps, the gas array, and the primary productivity incubation array were deployed and recovered without incidents. The arrays drifted westward. Two plankton net tows were conducted during the day, and two at night. The PRR was deployed as planned. The ADCP ran without interruption throughout the cruise, as well as the thermosalinograph, and the ship's two anemometers.

Winds were easterlies of about 20-25 kt during the cruise, decreasing to near zero the last day of the cruise. We arrived back at Snug Harbor on December 16 at 0800. Full off-load took place immediately.
4.0 RESULTS

4.1 Hydrography

4.1.1 2005 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 2005 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 2005 are presented in Figures 6.1.4. Station Kaena was not visited during HOT-168, 169, 172, and 176 because of time constraints.

The potential temperature, salinity and oxygen profiles obtained from the deep casts at Station ALOHA during 2005 are presented in Figures 6.1.5-7.

4.1.2 Time-series Hydrography, 1988-2005

The hydrographic data collected during the first seventeen years of HOT are presented in a series of contour plots (Figures 6.1.8-23). These figures show the data collected in 2005 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 2005. 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 2005. 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, and during 1996. 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, and in early 2005; and increasing again by the end of 2002, early 2003, late 2003, and early 2004. This increase is also present in deeper layers reaching 200 dbar (Figure 6.1.10). The salinity decrease during the second half of 2004 reached values comparable to those during 1996.

The salinity maximum is generally found between 50 and 150 dbar, and within the range 24-25 σθ. A salinity maximum region extends to the sea surface in the later part of 1990, 1993 and during 1998 throughout the early months of 2002, during late 2002 and early 2003, and again in the late part of 2003, early 2004, and late 2004, 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. In 2005 the salinities decreased to values comparable to those in 1998. 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 this 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 over the last 10 years.
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 and in the summer of 1996. 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.

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.

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 record high values in mid-2004, to decrease again to values similar to those in 2002 by the end of 2005.

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, and late-2003. 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 (Lukas and Santiago-Mandujano, in prep.). 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 \( \sigma_0 \) 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 \( \sigma_0 \) (Figure 6.1.24). A decrease in
[nitrate + nitrite] began in late 1994, with a comparable increase from mid-1995 through early 1996. The maximum decrease appears to be about 1 µmol kg$^{-1}$ below 27.5 $\sigma_0$ where nitrate concentrations are about 40 µmol 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 µmol kg$^{-1}$ for samples with a concentration of 40 µmol kg$^{-1}$. Hence, the 1 µmol kg$^{-1}$ decrease seen during 1995 is well within the precision level for the concentrations observed. However, the amount of the decrease could be approaching the accuracy limits of [nitrate + nitrite] measurements. This low [nitrate + nitrite] episode is accompanied by an increase in oxygen concentration (Figure 6.1.24).

Intermediate water SRP (between 27.0-27.8 $\sigma_0$) reached lowest 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). Decreases in phosphate in the deeper waters could persist for long periods of time as the oceanic ecosystem associated with Station ALOHA has been hypothesized to be phosphorous limited in recent years (Karl, 1995). Oxygen concentrations between 27.0-27.8 $\sigma_0$ vary during the decrease of phosphate from early 1994 through 1997 (Figure 6.1.24) 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 2005 HOT and mooring 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 cruises HOT-169, 170, 173, 174, and 175 were flagged as uncalibrated due to adverse warming as a result of water passing the pump before the remote temperature sensor. Additionally the conductivities measured during these cruises were affected by a faulty valve connected to the freshwater plumbing, which leaked slightly when pressurized allowing fresh water to enter the thermosalinograph chamber.

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.

Salinities at station ALOHA were higher than 35.2 during the fourth cruise (June) of the year, but they were generally below this value for the remainder of the cruises. During HOT-171 the salinity was observed to vary zonally between 157.95 W and 158.1 W decreasing from approximately 35.1 to 34.94. A similarly during HOT-172 salinity was seen to decrease from 35.15 to 34.95 but increase as the ships positioned towards the west.

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.

One National Data Buoy Center (NDBC) meteorological buoy (#51001) is located 400 km west of ALOHA at 23.4°N, 162.3°W (Figure 1.1). This buoy collects hourly observations of air temperature, sea surface temperature, atmospheric pressure, wind speed and direction and significant wave height. The coherence of the data from Buoy #51001 with the data collected on HOT cruises was examined and reported in Tupas et al. (1993). We concluded from these analyses, that the data from this buoy can be used to get useful estimates of air temperature, sea surface temperature and atmospheric pressure at Station ALOHA when the station is not occupied. 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 buoy #51001 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 6.4.1a to j) and velocity as a function of latitude and depth during transit to and from Station ALOHA and Station 6, combined (Figures 6.4.2a to j). 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 1988-2005 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 100 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 Titration Alkalinity

Time-series of mixed-layer titration alkalinity and DIC from 1988-2005 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 titration alkalinity is shown in Figure 6.5.4.

Mixed layer titration alkalinity normalized to 35 ppt salinity averages approximately 2303 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 titration alkalinity normalized to salinity remains constant in both the North and South Pacific subtropical gyres. In contrast to titration alkalinity, the concentration of DIC varies seasonally and interannually. DIC in the mixed layer is highest in March and April and lowest in September and October. This oscillation results from winter mixing of DIC rich waters from below and biological drawdown of CO₂ in the shallow summer mixed layers (Ishii, M. et al., 2001). Using this data, Dore et al. (2003) found a significant decrease in the strength of the CO₂ sink between 1989 and 2001 due to changes in regional precipitation and evaporation patterns brought on by climate variability.

4.5.3 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 2005. The upper 100 m is generally depleted in [nitrate + nitrite] with values usually not exceeding 5 nmol kg⁻¹. A contour plot of LLN from 0-100 dbar during the 1989-2005 time period is shown in Figure 6.5.6.

Dissolved inorganic P (DIP) was analyzed using the MAGnesium Induced Co-precipitation (MAGIC) method (Karl and Tien 1992). MAGIC improves both the sensitivity (detection limit ~ 1 nmol P l⁻¹) and the precision of the low level P (LLP) determination in oligotrophic seawaters. Figure 6.5.7 presents the low-level SRP data from 2005. At depths shallower than 100 m, SRP is typically less than 100 nmol kg⁻¹. A contour plot of LLP from 0-100 dbar during the period 1989-2005 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. It has been suggested that this long-term, decadal-scale reduction in DIP is a result of selection for N₂ fixation microorganisms with an attendant shift from a N-controlled to a P-controlled ecosystem (Karl et al. 2001). Despite this general reduction in DIP concentration, there appear to be aperiodic injections of DIP (for example in early 1995 and less dramatic increases in 1998, 2000 and 2001). The mechanism(s) controlling these inventory enhancements is not well resolved in the HOT field data.
4.5.4 Dissolved Organic Matter

A contour plot of dissolved organic carbon (DOC) from 0 to 1000 dbar over the 1988-2005 time period is presented in Figure 6.5.9 and contour plots of dissolved organic nitrogen (DON) and phosphorus (DOP) from 0 to 1000 dbar over the 1988-2000 time period are presented in Figures 6.5.10-6.5.11. DOC concentrations are typically about 70-110 µmol kg\(^{-1}\) at the surface and decrease to about 40-50 µmol kg\(^{-1}\) at 800 m. DON is typically 5-6 µmol kg\(^{-1}\) at the surface, decreasing to about 2 µmol kg\(^{-1}\) at 800 m. DOP is about 0.2-0.3 µmol kg\(^{-1}\) at the surface and decreases to <0.05 µmol kg\(^{-1}\) at 800 m. All three organic nutrients exhibit substantial interannual variability.

4.5.5 Particulate Bioelements

4.5.5.1 Particulate Carbon, Nitrogen and Phosphorus

Particulate carbon (PC), nitrogen (PN) and phosphorus (PP) concentrations in the surface ocean over the 17 years of the program are shown in Figures 6.5.12-6.5.17. 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.

4.5.5.2 Particulate Biogenic Silica

Particulate biogenic silica (PSi) concentrations in the surface ocean over the last 9 years of the program are shown in Figure 6.5.18 and Figure 6.5.19. 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 6.5.22).

4.5.6 Pigments

4.5.6.1 Standard Fluorometric Method

A contour plot of chlorophyll \(a\) concentrations measured using standard fluorometric techniques from 0 to 200 dbar during 1988-2005 is shown in Figure 6.5.20. 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.
4.5.6.2 High Performance Liquid Chromatography

Contour plots of HPLC-determined pigment concentrations from 0 to 200 dbar during 1988-2005 are shown in Figures 6.5.21-6.5.23. The pigments have been segregated into three chromophore classes: chlorophylls (chlorophyll \(a\), chlorophyll \(b\), and chlorophyll \(c\); Figure 6.5.21), photosynthetic carotenoids (19'-butanoyloxyfucoxanthin, fucoxanthin, and 19'-hexanoyloxyfucoxanthin; Figure 6.5.22) and photo-protective carotenoids (diadinoxanthin, zeaxanthin, and \(\alpha/\beta\)-carotene; Figure 6.5.23).

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

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

4.5.6.3 Chlorophyll \(a\), \(b\), \(c\)

Contour plots of TD-700 analyzed chlorophylls \(a\), \(b\) and \(c\) from 0 to 200 meters are shown in Figure 6.5.24. For every pigment, a maximum is observed at approximately 120 meters. Chlorophyll \(a\) concentrations by fluorometry show an annual cycle with winter maxima and summer minima. During HOT-116 (June 2000), chlorophyll \(a\) concentrations increased dramatically in the upper 45 m of the water. This feature appears associated with a large bloom of diatoms, as evidenced from the sharp increases in chlorophyll \(c\), particulate silica (Figure 6.5.19) and fucoxanthin (Figure 6.5.22).
4.5.6.4 Phycoerythrin

Contour plots of the 0.4µm, 5µm and 10µm fractions of phycoerythrin from 0 to 200 meters are shown in Figure 6.5.25. While the > 0.4µm and > 5µm fractions do not appear to show any type of seasonality or gradation in the upper ocean, the > 10µm fraction appears to show a late fall bloom of either *Trichodesmium* or aggregates containing cyanobacteria.

4.5.7 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 6.5.26). 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 ¹⁴C incubations and pigment determinations for samples collected from CTD casts in 2005 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 17 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 (± sd) depth integrated primary production for the entire 17 year data set is 511 ± 143 mg C m⁻² d⁻¹. Although this value is higher than historical measurements for the oceanic central gyres (Ryther 1969), it is consistent with more recent measurements (Martin et al., 1987; Laws et al., 1989; Knauer et al., 1990).

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

<table>
<thead>
<tr>
<th>HOT</th>
<th>LICOR Irradiance (E m⁻² d⁻¹)</th>
<th>PRR Irradiance (E m⁻² d⁻¹)</th>
<th>Pigments (mg m⁻²)</th>
<th>Incubation Duration (hrs)</th>
<th>Light Assimilation Rates (mg C m⁻² d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Chl a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>167</td>
<td>11.55</td>
<td>11.75</td>
<td>16.9</td>
<td>29.6</td>
<td>11.25</td>
</tr>
<tr>
<td>168</td>
<td>14.34</td>
<td>14.53</td>
<td>18.2</td>
<td>30.2</td>
<td>12.25</td>
</tr>
<tr>
<td>169</td>
<td>46.54</td>
<td>45.77</td>
<td>23.5</td>
<td>38.8</td>
<td>13.00</td>
</tr>
<tr>
<td>170</td>
<td>55.44</td>
<td>55.37</td>
<td>24.2</td>
<td>38.8</td>
<td>13.50</td>
</tr>
<tr>
<td>171</td>
<td>56.02</td>
<td>NA</td>
<td>20.2</td>
<td>35.8</td>
<td>13.75</td>
</tr>
<tr>
<td>172</td>
<td>51.58</td>
<td>52.27</td>
<td>24.8</td>
<td>40.3</td>
<td>13.25</td>
</tr>
<tr>
<td>173</td>
<td>46.50</td>
<td>NA</td>
<td>28.5</td>
<td>43.2</td>
<td>13.00</td>
</tr>
<tr>
<td>174</td>
<td>34.12</td>
<td>31.47</td>
<td>24.2</td>
<td>37.8</td>
<td>12.00</td>
</tr>
<tr>
<td>175</td>
<td>35.97</td>
<td>32.25</td>
<td>23.1</td>
<td>39.3</td>
<td>12.75</td>
</tr>
<tr>
<td>176</td>
<td>30.19</td>
<td>28.75</td>
<td>24.9</td>
<td>38.9</td>
<td>12.00</td>
</tr>
</tbody>
</table>
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 1988-2005 time period. All four fluxes show large month-to-month and interannual variations. The magnitudes of PC and PN fluxes vary by about a factor of five, while PP and PSi fluxes varies by about a factor of 20. These particle flux measurements are consistent in magnitude with those measured in the central North Pacific Ocean during the VERTEX program (Martin et al., 1987; Knauer et al., 1990). However, the HOT data set reveals interannual changes not documented by earlier studies. Of particular note is the change from a more variable, high-flux time period (1988-1991) to a low-flux low-variability regime (1992-1996). There is a suggestion in the 1997-2005 data that particle fluxes may have increased in magnitude and variability.

Table 4.2: Station ALOHA 2005 sediment trap flux data

<table>
<thead>
<tr>
<th>HOT</th>
<th>PC Flux (mg m² d⁻¹)</th>
<th>PN Flux (mg m² d⁻¹)</th>
<th>PP Flux (mg m² d⁻¹)</th>
<th>PSi Flux (mg m² d⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
<td>SD</td>
</tr>
<tr>
<td>167</td>
<td>23.7</td>
<td>4.8</td>
<td>3.53</td>
<td>0.70</td>
</tr>
<tr>
<td>168</td>
<td>32.3</td>
<td>4.5</td>
<td>4.65</td>
<td>0.48</td>
</tr>
<tr>
<td>169</td>
<td>32.8</td>
<td>5.4</td>
<td>5.37</td>
<td>0.84</td>
</tr>
<tr>
<td>170</td>
<td>30.0</td>
<td>5.3</td>
<td>4.10</td>
<td>0.61</td>
</tr>
<tr>
<td>171</td>
<td>35.2</td>
<td>2.8</td>
<td>4.87</td>
<td>0.60</td>
</tr>
<tr>
<td>172</td>
<td>46.4</td>
<td>9.4</td>
<td>7.15</td>
<td>1.56</td>
</tr>
<tr>
<td>173</td>
<td>28.6</td>
<td>3.0</td>
<td>4.42</td>
<td>0.60</td>
</tr>
<tr>
<td>174</td>
<td>15.7</td>
<td>1.4</td>
<td>2.21</td>
<td>0.16</td>
</tr>
<tr>
<td>175</td>
<td>19.0</td>
<td>3.3</td>
<td>3.22</td>
<td>0.58</td>
</tr>
<tr>
<td>176</td>
<td>24.0</td>
<td>5.7</td>
<td>3.44</td>
<td>0.85</td>
</tr>
</tbody>
</table>

4.7 Optical Measurements

4.7.1 Solar Irradiance

Incident irradiance (400-700 nm wavelength band) measured using a LICOR LI-1000 during the cruise is shown in Figures 6.7.1a-j (upper panel). Incident irradiance is dependent on cloud cover, so it can potentially vary greatly from cruise-to-cruise or even day-to-day. But in general, as would be expected, higher values are measured during the summer months (HOT-170 & HOT-171) and lower values in the winter months (HOT-167 & HOT-176). To help interpret the results, integrated incident irradiance measured during the Primary Production incubation period is included in Table 4.1.
4.7.2 Downwelling Irradiance and Upwelling Radiance

Profiles of photosynthetically available radiation (PAR) and PAR attenuation coefficient ($K_{\text{PAR}}$) measured using a Biospherical PRR-600 are shown in Figures 6.7.1a-j (lower panels). Due to the tendency for the instrument to tilt back-and-forth when brought up through the water column, only the downcast profiles are included. Figure 6.7.2 shows time-series of the 1 % light level and $K_{\text{PAR}}$ during the 8 years we’ve been collecting PRR data. Both vary seasonally. The average 1 % light level at Station ALOHA is about 106 m while the average $K_{\text{PAR}}$ between 100 & 150m is 0.0439 $m^{-1}$. Downwelling irradiance measured during the Primary Production incubation period is shown in Table 4.1. The results compare favorably with the integrals obtained using the LICOR LI-1000 which also measures PAR.

4.7.3 Fast Repetition Rate Fluorometry (FRRF)

In the North Pacific Subtropical Gyre (NPSG), aperiodic fluctuations in primary productivity are difficult to capture using the in situ $^{14}$C-primary production measurements. 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 6.7.3a-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.

The FRRF-derived initial slope of the P vs. E curve ($\alpha$) (Figure 6.7.3a-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 $\Phi C$ (quantum yield of photosynthesis) was low (0.0016 mol C mol quanta$^{-1}$) throughout the year, with maxima in the DCML region. $\Phi C$ was significantly related to changes in functionally reaction centers (linear) and in $\alpha$ (exponential), and to a lesser extent to $F_{V}/F_{M}$ (linear). Significant ($\Delta = \pm 100\%$) daily variations in primary productivity (Figure 6.7.3a-g, right panel), driven by changes in $\alpha$, 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 ($\alpha$), and not the efficiency of light utilization ($F_{V}/F_{M}$), appears to be the physiological parameter driving $\Phi C$ variations, daily productivity and to some extent the observed aperiodic variation in the NPSG. (Corno et al. 2006)

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 10^5 cells ml^-1. In most cases bacterial numbers decrease with depth although there are some profiles where the numbers remain fairly constant with depth throughout the euphotic zone. *Prochlorococcus* cells are found at concentrations ranging from around 0 to 2 x 10^5 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 x 10^3 ml^-1, and decrease with depth with a subsurface maxima between 50 and 100 m. The abundances of picoeukaryotes typically range from 1 to 3 x 10^3 ml^-1, and similar to *Synechococcus*, the eukaryote populations generally decline with depth, occasionally exhibiting a subsurface maximum.

4.9 **Zooplankton Community Structure**

Temporal variation in mesozooplankton biomass during 2004 is presented in Figures 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 and 13% during the night.

Nighttime dry weight zooplankton biomass during 2004 (mean = 1.36 g DW m^-2 (standard deviation, s = 0.327 g DW m^-2)) was approximately 1.63 times that of zooplankton collected during the day (mean = 0.887 g DW m^-2 (s = 0.268 g DW m^-2). Wet weight biomass of zooplankton differed similarly during the night (mean = 10.4 g WW m^-2 (standard deviation, s = 2.48 g WW m^-2)) and day (mean = 7.43 g WW m^-2 (standard deviation, s = 2.31 g WW m^-2)), and night wet weights were 1.51 times day wet weights. 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 (Student’s T-test, n=11, p<0.01), and was caused by the upward migration of deep-living zooplankton and micronekton after sunset.

Mesozooplankton dry weight biomass averages during HOT year 16 are slightly higher than averages for all eleven years of the zooplankton program (1994 – 2004: night mean = 1.10 g DW m^-2 (s = 0.341 g DW m^-2); day mean = 0.705 g DW m^-2 (s = 0.277 g DW m^-2)). Nighttime dry weight biomass was significantly greater during year 16 (2004) than during 1994, 1995, 1996, 1997, 1998 and 1999 (Mann-Whitney U test, n<12, p<0.05). Nighttime biomass during 2000, 2001, 2002 and 2003 did not differ significantly from year 15 (2003). This pattern was similar for daytime zooplankton biomasses. Daytime dry weight biomass was significantly greater during year 16 (2004) than during 1994, 1995, 1996, 1997 and 1999 (Mann-Whitney U test, n<12, p<0.05), whereas daytime biomass during 1998, 2000, 2001, 2002 and 2003 did not differ significantly from year 16 (2004).
5.0 REFERENCES


6.0 FIGURES

6.1 Hydrography

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

**Figure 6.1.2a-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 $\sigma_0$ 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 ($\sigma_0$) as a function of pressure for the cast at Station Kahe for each HOT cruise. [Upper right panel] Plot of CTD and bottle dissolved oxygen and salinity as a function of potential temperature for water samples at Station Kahe. [Lower left panel] Plot of temperature, salinity, oxygen, and $\sigma_0$ as a function of pressure at Station Kaena (except for b, c, f, and j). [Lower right panel] Plot of CTD and bottle salinity and oxygen as a function of potential temperature at Station Kaena (except for b, c, f, and j).

**Figure 6.1.5**: [Upper panel] Potential temperature versus pressure for all deep casts in 2005. [Lower panel]: Potential temperature versus pressure deeper than 2500 dbar for all deep casts in 2005.

**Figure 6.1.6**: [Upper panel] Salinity versus potential temperature for all deep casts in 2005. [Lower panel]: Salinity versus potential temperature for all deep casts in 2005 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 2005. [Lower panel] Oxygen versus potential temperature for all deep casts in 2005 in the 1-5 °C range.

**Figure 6.1.8**: Contour plot of CTD potential temperature versus pressure for HOT cruises 1-176.

**Figure 6.1.9**: Contour plot of $\sigma_0$, calculated from CTD pressure, temperature and salinity, versus pressure for HOT cruises 1-176.
**Figure 6.1.10**: Contour plot of CTD salinity versus pressure for HOT cruises 1-176.

**Figure 6.1.11**: Contour plot of CTD salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-176. 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 1-176. 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 1-176. 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 1-176. 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 1-176. 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 1-176. 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 1-176. 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 1-176.

**Figure 6.1.19**: Contour plot of soluble reactive phosphorus versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-176.

**Figure 6.1.20**: Contour plot of soluble reactive phosphorus versus pressure for HOT cruises 1-176. 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 1-176. 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 1-176. 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 1-176. 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 1-176 (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 each HOT cruise in 2005. 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 171, 173, 174, and 175 were flagged uncalibrated due to a problem with the R/V Kilo Moana thermosalinograph system (see text).

Figure 6.2.2a-j: Navigation data during each HOT cruise in 2005: 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 2005 HOT cruises (open circles), and NDBC buoy #51001 hourly measurements throughout the year (continuous line). [Lower panel] Sea surface temperature measured from a bucket sample while at Station ALOHA for 2005 HOT cruises (open circles), NDBC buoy #51001 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 2005 HOT cruises (open circles), and NDBC buoy #51001 hourly measurements throughout the year (continuous line). [Lower panel] Wet bulb air temperature while at Station ALOHA for 2005 HOT cruises.

Figure 6.3.3: [Upper panel] Sea surface temperature minus dry air temperature while at Station ALOHA for 2005 HOT cruises (open circles), and NDBC buoy #51001 hourly measurements throughout the year (continuous line). [Lower panel] Relative humidity at Station ALOHA for 2005 HOT cruises.

Figures 6.3.4a-j: [Upper panel] True winds measured at Station ALOHA for 2005 HOT cruises. [Middle panel] Continuous true wind record from the ship’s anemometer during HOT cruises. [Lower panel] True winds measured by NDBC buoy #51001. The orientation of the arrows indicates the wind direction; up is northward, right is eastward.

6.4 ADCP Measurements

Figures 6.4.1a-j: Velocity fields at Station ALOHA. Top panel shows hourly averages at 20-m depth intervals 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-j: Velocity fields on the transits to and from Station ALOHA and Station 6. 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 1-176 from 0-200 dbar. Solid dots indicate water column sample locations.

Figure 6.5.2: [Upper panel] Time series of mean mixed layer titration alkalinity (normalized to 35 ppt salinity) for HOT cruises 1-176. [Lower panel] Mixed layer dissolved inorganic carbon (normalized to 35 ppt salinity) for HOT cruises 1-176. 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 1-176 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 titration alkalinity versus pressure for HOT cruises 1-176 from 0-200 dbar. Solid dots indicate water column sample locations. [Lower panel] Contour plot of titration 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 2005 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 1-176. [Lower panel] 0-100 dbar integral of LLN at Station ALOHA for HOT cruises 1-176.

Figure 6.5.7: Depth profile from 0-250 dbar of low-level soluble reactive phosphorus at Station ALOHA for 2005 HOT cruises by the high-sensitivity magnesium induced coprecipitation (MAGIC) method.

Figure 6.5.8: [Upper panel] Contour plot from 0-100 dbar of low-level soluble reactive phosphorus at Station ALOHA for HOT cruises 1-176. [Lower panel] 0-100 dbar integral of LLP at Station ALOHA for HOT cruises 1-176.

Figure 6.5.9: Contour plot from 0-1000 dbar of dissolved organic carbon at Station ALOHA for HOT cruises 1-176. Solid dots indicate water column sample locations.
**Figure 6.5.10:** Contour plot from 0-1000 dbar of dissolved organic nitrogen at Station ALOHA for HOT cruises 1-121. Solid dots indicate water column sample locations.

**Figure 6.5.11:** Contour plot from 0-1000 dbar of dissolved organic phosphorus at Station ALOHA for HOT cruises 1-121. Solid dots indicate water column sample locations.

**Figure 6.5.12:** [Upper panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-176 from 0-50 dbar. [Lower panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-176 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 carbon at Station ALOHA for HOT cruises 1-176. Solid dots indicate water column sample locations.

**Figure 6.5.14:** [Upper panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-176 from 0-50 dbar. [Lower panel] Mean concentrations of particulate nitrogen at Station ALOHA for HOT cruises 1-176 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 nitrogen at Station ALOHA for HOT cruises 1-176. Solid dots indicate water column sample locations.

**Figure 6.5.16:** [Upper panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-176 from 0-50 dbar. [Lower panel] Mean concentrations of particulate phosphorus at Station ALOHA for HOT cruises 1-176 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.17:** Contour plot from 0-350 dbar of particulate phosphorus at Station ALOHA for HOT cruises 1-176. Solid dots indicate water column sample locations.

**Figure 6.5.18:** [Upper panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-176 from 0-50 dbar. [Lower panel] Mean concentrations of particulate silica at Station ALOHA for HOT cruises 79-176 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.19:** Contour plot from 0-200 dbar of particulate biogenic silica at Station ALOHA for HOT cruises 79-176. Solid dots indicate water column sample locations.

**Figure 6.5.20:** Contour plot from 0-200 dbar of fluorometric chlorophyll *a* concentrations at Station ALOHA for HOT cruises 1-176. Solid dots indicate water column sample locations.

**Figure 6.5.21:** Contour plots from 0-200 dbar of HPLC chlorophyll (chlorophyll *a*, chlorophyll *b* & chlorophyll *c*) concentrations at Station ALOHA for HOT cruises 1-176.

**Figure 6.5.22:** Contour plots from 0-200 dbar of HPLC photosynthetic carotenoid (19'-butanoyloxyfucoxanthin, fucoxanthin & 19'-hexanoyloxyfucoxanthin) concentrations at Station ALOHA for HOT cruises 1-176.
**Figure 6.5.23:** Contour plots from 0-200 dbar of HPLC photo-protective carotenoid (diadinoxanthin, zeaxanthin & α- plus β-carotene) concentrations at Station ALOHA for HOT cruises 1-176.

**Figure 6.5.24:** Contour plots from 0-200 dbar of TD-700 analyzed chlorophyll a, b & c concentrations at Station ALOHA for HOT cruises 111-176. Solid dots indicate water column sample locations.

**Figure 6.5.25:** Contour plots from 0-200 dbar of TD-700 analyzed phycoerythrin concentrations (0.4µm, 5µm & 10µm fractions) at Station ALOHA for HOT cruises 111-176. Solid dots indicate water column sample locations.

**Figure 6.5.26:** Contour plot from 0-350 dbar of particulate adenosine 5'-triphosphate concentrations at Station ALOHA for HOT cruises 1-176. 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 1988-2005. Filled circles and crosses indicate in situ and on deck incubations, respectively. Solid line represents the average production (511 mg C m⁻² d⁻¹), dashed lines are ± one standard deviation (143 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 1-176. 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 1988-2005. Error bars represent the standard deviation of determinations from triplicate particle interceptor traps.

6.7 Optical Measurements

**Figure 6.7.1a–j:** [Upper panel] Incident irradiance (400-700 nm wavelength band) measured using a Li-COR LI-1000 data logger during each cruise. The red, blue & green lines represent the minimum, average & maximum light value respectively of 10-minute intervals. The total incident irradiance measured when the primary production array was out (represented by the light-blue shaded area) is also calculated and included at the top of each figure. [Lower left panel] Photosynthetically available radiation (PARα : derived from K_{PAR} using the average downcast surface light) versus depth for every profile at Station ALOHA. [Lower right panel] PAR attenuation coefficient (K_{PAR}) versus depth for every profile at Station ALOHA.
Figure 6.7.2: [Upper panel] Depth of the 1% surface PAR light level for HOT cruises 90-176. The solid red light represents the average 1% surface PAR light depth (106.3m) at Station ALOHA. [Lower panel] Mean PAR attenuation coefficient ($K_{\text{PAR}}$) for HOT cruises 90-176 from 100-150m. The solid red line represents the average $K_{\text{PAR}}$ (.0439 m$^{-1}$) at Station ALOHA.

Figure 6.7.3a-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)

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 2005.

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 23-176. 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 2005.

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 23-176. 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 during 2004. Nighttime (blue) and daytime (red) biomass are plotted. Error bars are the standard deviation for three replicate tows.
7.0 HOT PROGRAM PRESENTATIONS AND PUBLICATIONS

The following is a listing of Presentations & Publications as of November 2007. 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.


<table>
<thead>
<tr>
<th>Number</th>
<th>Year</th>
<th>Authors</th>
<th>Title</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>137</td>
<td>2006</td>
<td>Church, M. J., C. Mahaffey, A. A. Fong, J. P. Zehr, D. M. Karl</td>
<td>Time series investigations into the dynamics of nitrogen fixing bacteria and rates of nitrogen fixation at Station ALOHA.</td>
<td>ASLO/TOS/AGU Ocean Sciences Meeting, Honolulu, HI, February 2006.</td>
</tr>
<tr>
<td>142</td>
<td>2006</td>
<td>Fong, A. A., M. J. Church, D. M. Karl, R. Lukas, C. Mahaffey, J. P. Zehr</td>
<td>Diazotroph abundance and diversity during a large bloom in the oligotrophic North Pacific Gyre.</td>
<td>ASLO/TOS/AGU Ocean Sciences Meeting, Honolulu, HI, February 2006.</td>
</tr>
</tbody>
</table>

99


7.2 Invited/Contributed Book Chapters and Refereed Publications


63. 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, 1619-1628.


108. 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.


197. 2007 Dore, J. E., R. M. Letelier, M. J. Church, R. Lukas and D. M. Karl. Summer phytoplankton blooms in the oligotrophic North Pacific Subtropical Gyre: Historical perspective and recent observations. Progress in Oceanography, in press.


### 7.3 Submitted Papers


### 7.4 Thesis and Dissertations


7.5 Data Reports and Manuals


### 7.6 Newsletters


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

7.7 Symposia

1) Presentations from the "HOT Program: Progress and Prospectus" symposium, 3-4 June 1992, East-West Center, Honolulu, HI
   a) Campbell, L. Bacterial numbers by flow cytometry: A new approach
   b) Chiswell, S. Results from the inverted echo sounder network
   c) Christian, J. Biomass closure in the epipelagic zone
   d) Christian, J. Exoenzymatic hydrolysis of high molecular weight organic matter
   e) Dore, J. Annual and short-term variability in the distribution of nitrite at the US-JGOFS time-series station ALOHA
   f) Dore, J. and D. Hebel. Low-level nitrate and nitrite above the nutricline at Station ALOHA
   g) Firing, E. Ocean currents near ALOHA
h) Hebel, D., R. Letelier and J. Dore. Evaluation of the depth dependence and temporal variability of primary production at Station ALOHA
i) Hebel, D., R. Letelier and J. Dore. Past and present dissolved oxygen trends, methodology, and quality control during the Hawaii Ocean Time series
j) Hebel, D. and U. Magaard. Structure and temporal variability in biomass estimates at Station ALOHA
k) Houlihan, T. and D. Hebel. Organic and inorganic nutrients: Water column structure and usefulness in time-series analysis
l) Karl, D. Carbon utilization in the mesopelagic zone: AOU-DOC relationships
m) Karl, D. HOT/JGOFS program objectives: A brief overview
n) Karl, D. P-control of N2 fixation: An ecosystem model
o) Karl, D. Primary production and particle flux
p) Karl, D. et al. Review and re-assessment of core measurements: Suggestions for refinement and improvement
q) Karl, D. and G. Tien. Low-level SRP above the nutricline at Station ALOHA
s) Karl, D., K. Yanagi and K. Bjorkman. Composition and turnover of oceanic DOP
t) Letelier, R. Temporal variability of algal accessory pigments at Station ALOHA: What does it tell about the phytoplankton community structure at the DCML?
u) Letelier, R. and D. Hebel. Evaluation of fluorometric and HPLC chlorophyll a measurements at Station ALOHA
v) Letelier, R. and F. Santiago-Mandujano. Wind, sea surface temperature and significant wave height records from NDBC buoy #51001 compared to ship observations at Station ALOHA
w) Lukas, R. Water mass variability observed in the Hawaii Ocean Time-series
x) Sadler, D., C. Winn and C. Carrillo. Time-series measurements of pH: A new approach for HOT
y) Schudlich, R. Upper ocean gas modelling at Station ALOHA
z) Winn, C. DIC variability
aa) Winn, C. and C. Carrillo. DIC and alkalinity profiles and elemental ratios

2) Presentations from the "HOT Golden Anniversary Science Symposium," 16 November 1993, East-West Center, Honolulu, HI
a) Bingham, F. M. The oceanographic context of HOT
b) Campbell, L., H. Nolla, H. Liu and D. Vaulot. Phytoplankton population dynamics at the Hawaii Ocean Time series Station ALOHA
c) Campbell, L., H. Nolla and D. Vaulot. The importance of Prochlorococcus to community structure in the central North Pacific Ocean
d) Christian, J. Vertical fluxes of carbon and nitrogen at Station ALOHA
e) Dore, J. Nitrate diffusive flux cannot support new production during quiescent periods at Station ALOHA
f) Dore, J. Nitrification in lower euphotic zone at Station ALOHA: Patterns and significance
g) Firing, E. The north Hawaiian ridge current and other flows near ALOHA
h) Hebel, D. Temporal distribution, abundance and variability of suspended particulate matter (particulate carbon, nitrogen and phosphorus) at Station ALOHA -- Observations of a seasonal cycle
i) Karl, D., D. Hebel, L. Tupas, J. Dore and C. Winn. Station ALOHA particle fluxes and estimates of export production

j) Karl, D. M., R. Letelier, L. Tupas, J. Dore, D. Hebel and C. Winn. N2 fixation as a contributor to new production at Station ALOHA

k) Karl, D. M., G. Tien and K. Yanagi. Phosphorus dynamics at Station ALOHA

l) Kennan, S. C. Possibilities for stirring along the Hawaiian ridge

m) Krothapalli, S., Y. H. Li and F. T. Mackenzie. What controls the temporal variability of carbon flux at Station ALOHA?

n) Letelier, R. M. Inorganic carbon assimilation at Station ALOHA: Possible evidence of a change in carbon fluxes

o) Letelier, R. M. Spatial and temporal distribution of Trichodesmium sp. at Station ALOHA: How important are they?

p) Liu, H. and L. Campbell. Measurement of growth and mortality rates of Prochlorococcus and Synechococcus at Station ALOHA using a new selective inhibitor technique

q) Lukas, R. and F. Bingham. Annual and interannual variations of hydrographic properties observed in the Hawaii Ocean Time-series (HOT)

r) Lukas, R., F. M. Bingham and A. Mantyla. An anomalous cold event in the bottom water observed at Station ALOHA

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

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

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

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

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

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

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

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

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


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


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

f) Ducklow, H. Joint Global Ocean Flux Study -- Vision and Progress
g) Emerson, S., C. Stump and D. Wilber. Inert Gases as Tracers of Diapycnal Mixing in the Upper Ocean
h) Firing, E. Currents in the Vicinity of Station ALOHA: An Update
i) Fujieki, L. HOT-DOGS: A New Tool for HOT Program Data Base Analysis and Presentation
j) Hebel, D., L. Tupas and D. Karl. The Importance of Organic Exudates in the Measurement of Oligotrophic Ocean Primary Productivity
k) Karl, D., D. Hebel and L. Tupas. Regionalization of Station ALOHA
l) Karl, D., G. Tien, K. Bjorkman, K. Yanagi, R. Letelier, A. Colman and A. Thomson. The "Forgotten" Open Ocean P-Cycle
n) Landry, M., K. Selph and H. Al-Mutairi. Seasonal and Diurnal Variability of the Mesozooplankton Community at Ocean Station ALOHA
p) Liu, H., L. Campbell and H. Nolla. Prochlorococcus Growth Rate and Daily Variability at Station ALOHA
q) Lopez, M. and M. Huntley. Particle Concentrations at the Hawaii Ocean Time-series Station (Station ALOHA) Measured with an Optical Plankton Counter
r) Michaels, A. and A. Knap. The Bermuda Atlantic Time-Series Study (BATS): A View from the "Other" Ocean
t) Quay, P. and H. Anderson. A Dissolved Inorganic Carbon Budget at Station ALOHA
v) Scharek, R., M. Latasa, D. Karl and R. Bidigare. Vertical Flux of Diatoms at the JGOFS/BOCE 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
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. File names are chosen so that they may be copied to DOS machines without ambiguity. (DOS users should be aware that Unix is case-sensitive, and Unix extensions may be longer than 3 characters.)

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 user's commands are denoted by bold italicized text. The workstation's Internet address is mana.soest.hawaii.edu, or 128.171.154.9 (either address should work). All hydrographic information reside at this address. Biogeochemical and optical data are stored at ftp://ftp.soest.hawaii.edu/dkarl/hot.

1. At the Prompt >, type ftp 128.171.154.9 or ftp mana.soest.hawaii.edu.

2. When asked for your login name, type anonymous.

3. When asked for a password, type in your e-mail address.

4. To change to the HOT database, type cd /pub/hot. To view files type ls. A directory of files and subdirectories will appear.

5a. To obtain information about the database type get Readme.first. This will transfer an ASCII file to your system. Use any text editor to view it.

5b. To obtain a list of publications, type cd publication-list then get hotpub.lis.

5c. To obtain the HOT Field and Laboratory Protocols manual, type cd protocols then get 1142.asc.

5d. To obtain CTD data, type cd ctd/hot-#, where # is the HOT cruise of interest, then type mget *.ctd to transfer all the cruise CTD files to your system.

5e. To obtain water column data, type cd water, then get <filename> where the filename is hot#.gof (JGOFS data) or hot#.sea (PO data) and # is the HOT cruise of interest.
6. To exit type *bye*.

7. Biogeochemical and optical parameters are located on another server. At the prompt type

```
ftp 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

[www.soest.hawaii.edu/ HOT_WOCE/regis-form.html](http://www.soest.hawaii.edu/HOT_WOCE/regis-form.html). After submitting the registration form, an e-mail will be sent to the user with further instructions on how to access the data.

### 8.2 World Wide Web

The Hawaii Ocean Time-series Program maintains a site on the World Wide Web where data and information about the program and its activities can easily be accessed over the Internet. The address is [http://hahana.soest.hawaii.edu/hot/hot.html](http://hahana.soest.hawaii.edu/hot/hot.html). This web page is the springboard from which the homepages of the Physical Oceanography and Biogeochemistry & Ecology components (BEACH) 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/hot-dogs/interface.html](http://hahana.soest.hawaii.edu/hot/hot-dogs/interface.html). HOT-DOGS is a Matlab™ based program that displays HOT data in a graphical format as depth profiles, time-series or contour plots. In addition to its graphical capabilities, HOT-DOGS provides a means of downloading selected data parameters during specific years of the program. The user may perform the following:

- **Data Extraction**
  - *Bottle* (discrete)
  - *CTD* (continuous)
  - *Microzooplankton* (Nets)
  - *Particle Flux*
  - *Primary Production*

- **Display**
  - *Bottle* (discrete)
  - *CTD* (continuous)
- HPLC Pigments
- Particle Flux
- Primary Production
- Solar Irradiance
- PRR (Ir)radiance
- TSRB (Ir)radiance
- Inherent Optical Properties
- Fast Repetition Rate Fluorometry
- Underway Measurements
- User Defined

- **Standard Intervals** (vertical Water-Column)
  - Bottle (discrete)
  - HPLC Pigments
  - Primary Production
  - User Defined

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

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

- **Miscellaneous**
  - Mixed-layer Depth
  - Cruise Summary
Figure 6.1.1a
Figure 6.1.1b
Figure 6.1.1c
Station ALOHA HOT 170

Figure 6.1.1d
Figure 6.1.1e
Figure 6.1.1f
Figure 6.1.1g
Station ALOHA HOT 174

Figure 6.1.1h
Figure 6.1.1i
Figure 6.1.2a
Figure 6.1.2b
Figure 6.1.2d
Figure 6.1.2e
Figure 6.1.2f
Figure 6.1.2g
Figure 6.1.2h
Figure 6.1.2i
Figure 6.1.2j
Figure 6.1.3c
Figure 6.1.3d
Figure 6.1.3e
Figure 6.1.3f
Figure 6.1.3h
Figure 6.1.3j
Kahe Pt. HOT 167

Kaena Pt.

Figure 6.1.4a
Figure 6.1.4b
Figure 6.1.4c
Figure 6.1.4d
Figure 6.1.4e
Figure 6.1.4f
Figure 6.1.4g
Figure 6.1.4i
Figure 6.1.4j
Figure 6.1.6
Figure 6.1.7

HOT 167–176 WOCE deep casts

Potential Temperature [°C] vs. Oxygen [umol/kg]

Potential Temperature [°C] vs. Oxygen [umol/kg]
HOT 1–176 Bottle Salinity

Figure 6.1.12
HOT 1–176 Nitrate + Nitrite [umol/kg]

Figure 6.1.17
HOT 1–176 Nitrate + Nitrite [umol/kg]

Figure 6.1.18
HOT 1–176 Soluble Reactive Phosphorous [umol/kg]
HOT 1–176  Mean Oxygen between $\sigma_\theta$ 27.0 and 27.8

HOT 1–176  Mean [Nitrate+Nitrite] between $\sigma_\theta$ 27.0 and 27.8

HOT 1–176  Mean Soluble Reactive Phosphorus between $\sigma_\theta$ 27.0 and 27.8

Figure 6.1.24
Figure 6.2.1a
HOT-168 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.1b
Figure 6.2.1c
HOT−170 Thermosalinograph, o=CTD at 7 dbar, x=salinity bottle

Figure 6.2.1d
HOT−171 Thermosalinograph, $o$=CTD at 4 dbar, $x$=salinity bottle

Temperature ($^\circ$C)

Salinity

$\sigma_\theta$

Figure 6.2.1e
HOT-172 Thermosalinograph, \(\sigma = \text{CTD at 3 dbar}, \ x = \text{salinity bottle}\)

Temperature (°C)

Salinity

\(\sigma\)

August 2005 (GMT)

Figure 6.2.1f
HOT-173 Thermosalinograph, o=CTD at 7 dbar, x=salinity bottle

Temperature (°C)

Salinity

September 2005 (GMT)

Figure 6.2.1g
Figure 6.2.1h
Figure 6.2.1i
HOT-176 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

December 2005 (GMT)

Figure 6.2.1j
HOT−167 Navigation and Ship Speed

January–February 2005 (GMT)

Figure 6.2.2a
Figure 6.2.2b
Figure 6.2.2d
HOT−171 Navigation and Ship Speed

Figure 6.2.2e
Figure 6.2.2h
Figure 6.2.2i
Figure 6.3.1
HOT 167–176 Dry Bulb Air Temperature

Dry bulb air temperature (°C)

Wet Bulb Air Temperature

Wet bulb air temperature (°C)

Figure 6.3.2
HOT 167–176 SST – Dry Air Temperature

Relative Humidity

Figure 6.3.3
HOT 167 Shipboard True Winds, Observed

HOT 167−True Winds, from the continuous record of the ship

HOT 167 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4a
HOT 168 Shipboard True Winds, Observed

HOT 168−True Winds, from the continuous record of the ship

HOT 168 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4b
HOT 169 Shipboard True Winds, Observed

HOT 169 – True Winds, from the continuous record of the ship

HOT 169 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4c
HOT 170 Shipboard True Winds, Observed

HOT 170 − True Winds, from the continuous record of the ship

HOT 170 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4d
HOT 172 Shipboard True Winds, Observed

HOT 172−True Winds, from the continuous record of the ship

HOT 172 – True Winds, buoy data (23 24N, 162 18W)

5.0 m/s

Figure 6.3.4f
HOT 173 Shipboard True Winds, Observed

HOT 173–True Winds, from the continuous record of the ship

HOT 173 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4g
HOT 174 Shipboard True Winds, Observed

HOT 174−True Winds, from the continuous record of the ship

HOT 174 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4h
HOT 175 Shipboard True Winds, Observed

HOT 175–True Winds, from the continuous record of the ship

HOT 175 – True Winds, buoy data (23°24'N, 162°18'W)

Figure 6.3.4i
HOT 176 Shipboard True Winds, Observed

HOT 176−True Winds, from the continuous record of the ship

HOT 176 – True Winds, buoy data (23 24N, 162 18W)
Velocity On Station

Harmonic Analysis of Velocity

Figure 6.4.1a
Velocity On Station

HOT-168

Depth (m)

-300
-250
-200
-150
-100
-50
0

0.1 m/s

Harmonic Analysis of Velocity

Mean + trend

Semidiurnal 12.42 hours

Diurnal 24 hours

Figure 6.4.1b
Velocity On Station

Depth (m)

−300
−250
−200
−150
−100
−50
0

2005 Days

HOT−169

−0.1 m/s

Harmonic Analysis of Velocity

Depth (m)

mean + trend

semidiurnal

12.42 hours

diurnal

24 hours

0.1 m/s

Figure 6.4.1c
Velocity On Station

HOT-170

Depth (m)

-300
-250
-200
-150
-100
-50
0
0.1 m/s

2005 Days

Harmonic Analysis of Velocity

Depth (m)

mean + trend

0
-50
-100
-150
-200
-250
-300
0.1 m/s

12.42 hours
diurnal 24 hours

Figure 6.4.1d
Velocity On Station

Depth (m)

HOT−171

0.1 m/s

Harmonic Analysis of Velocity

Depth (m)

mean + trend semidiurnal 12.42 hours diurnal 24 hours

Figure 6.4.1e
Velocity On Station

2005 Days

Depth (m)

-300
-250
-200
-150
-100
-50
0
0.1 m/s

Harmonic Analysis of Velocity

mean + trend
semidiurnal 12.42 hours
diurnal 24 hours

depth (m)

-300
-250
-200
-150
-100
-50
0
-0.1 m/s

Figure 6.4.1f
Figure 6.4.1g
Figure 6.4.1h
Figure 6.4.1i
Figure 6.4.1j
Figure 6.4.2b
Figure 6.4.2c
Figure 6.4.2e
Figure 6.4.2f
Figure 6.4.2g
Figure 6.4.2h
Figure 6.4.2i
Figure 6.4.2j
HOT 1–176

Titration Alkalinity $[\mu$eq kg$^{-1}$] (35 ppt)

Dissolved Inorganic Carbon $[\mu$mol kg$^{-1}$] (35 ppt)

Sampling Date

Figure 6.5.2
HOT 1–176 Dissolved Inorganic Carbon [μmol kg⁻¹]

HOT 1–176 Dissolved Inorganic Carbon [μmol kg⁻¹] (35 ppt)

Figure 6.5.3
HOT 1–176 Titration Alkalinity [μeq kg⁻¹]

Figure 6.5.4
Figure 6.5.5
Figure 6.5.7
Figure 6.5.7 continued
HOT 1–176 Low-Level Phosphorus [nmol kg⁻¹]

Pressure [dbars]

Sampling Date

LLP [nmol m⁻²]

Figure 6.5.8
Figure 6.5.12
HOT 1–176 Particulate Carbon [μmol kg⁻¹]

Figure 6.5.13
HOT 1–176 (0–50 dbar means)

Particulate Nitrogen [μmol kg⁻¹]

Sampling Date

89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05

HOT 1–176 (50–100 dbar means)

Particulate Nitrogen [μmol kg⁻¹]

Sampling Date

89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05

Figure 6.5.14
HOT 1–176 (0–50 dbar means)

HOT 1–176 (50–100 dbar means)

Figure 6.5.16
HOT 1-176 Particulate Phosphorus [nmol kg\(^{-1}\)]

Figure 6.5.17
Figure 6.5.18
HOT 1–176 Diadinoxanthin [µg m⁻³]

HOT 1–176 Zeaxanthin [µg m⁻³]

HOT 1–176 Carotenes [µg m⁻³]

Figure 6.5.23
HOT 111–176 TD–700 Chlorophyll a $[\text{mg m}^{-3}]$

HOT 111–176 TD–700 Chlorophyll b $[\text{mg m}^{-3}]$

HOT 111–176 TD–700 Chlorophyll c $[\text{mg m}^{-3}]$

Figure 6.5.24
HOT 111–176 Phycoerythrin 0.4 μm fraction [ng l⁻¹]

HOT 111–176 Phycoerythrin 5 μm fraction [ng l⁻¹]

HOT 111–176 Phycoerythrin 10 μm fraction [ng l⁻¹]

Figure 6.5.25
Figure 6.6.1
Figure 6.6.3
HOT–168, int = 14.34 [E m^{-2} d^{-1}]

Figure 6.7.1b
HOT–169, int = 46.54 [E m\(^{-2}\) d\(^{-1}\)]

Figure 6.7.1c
HOT–170, int = 55.44 [E m\(^{-2}\) d\(^{-1}\)]
HOT–171, int = 56.02 [E m⁻² d⁻¹]

Figure 6.7.1e
HOT–173, int = 46.50 [E m\(^{-2}\) d\(^{-1}\)]

![Graph of Incident Irradiance](image)

![Graph of PAR and KPAR](image)

Figure 6.7.1g
HOT–175, int = 35.97 [E m\(^{-2}\) d\(^{-1}\)]

Figure 6.7.1i
HOT-176, int = 30.19 \text{ [E m}^{-2} \text{ d}^{-1}] \)
Figure 6.7.2
Figure 6.7.3a
Figure 6.7.3b
Figure 6.7.3c
Figure 6.7.3d
Figure 6.7.3e
Figure 6.7.3f
Figure 6.7.3g
Figure 6.8.1
Figure 6.8.1 continued
HOT 23–176 Heterotrophic Bacteria [\# * 10^5/ml]

HOT 23–176 Prochlorococcus [\# * 10^5/ml]

Figure 6.8.2
Figure 6.8.3 continued
Year 16 (2004) HOT Zooplankton Dry Weight Biomass

Year 16 (2004) HOT Zooplankton Wet Weight Biomass

Figure 6.9.1