Hawaii Ocean Time-series Program

DATA REPORT 13

2001

October 2004
Hawaii Ocean Time-series
Data Report 13: 2001
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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, primary production, plankton community structure, and particle sedimentation rates are made on each cruise.

This document reports the data collected in 2001. However, we have included some data from 1988-2000 to place the 2001 measurements within the context of our 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 Sun 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 2001 cruises sponsored by the HOT program. Special thanks are due to Colleen Allen, Karin Björkman, Anne Gasc, Tom Gregory, Dale Hebel, Jeremiah Johnson, Noel Larson, Paul Morris and Mark Valenciano for the tremendous amount of time and effort they have put into the program. Special thanks are given to Lisa Lum & Nancy Paquin for their excellent administrative support of the program, Sharon DeCarlo for programming and data management, Siang Chyn Lim, Ishuan Wu, and Jareus Sylva for CTD processing, and June Firing for ADCP processing. Ursula Magaard & Tom Gregory performed many of the core chemical analyses. Ted Walsh & Anne Gasc performed the nutrient analyses, Noel Larson performed the salinity measurements; and Patrick Ho and Brandon Shima provided additional technical support. We gratefully acknowledge the support from Nordeen Larson and Ken Lawson of 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 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.

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 2001 work are NSF grants OCE-9811921 (Lukas) and OCE-9617409 (Karl, Bidigare, Hebel, Landry and Tupas).
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 Hawaiian waters. In July 1988, these proposals were funded by the National Science Foundation and Station ALOHA 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 biogeochemical (JGOFS) 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 2001

<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>JGOFS Carbon Component</td>
</tr>
<tr>
<td>Eric Firing</td>
<td>ADCP Component</td>
</tr>
<tr>
<td>David M. Karl</td>
<td>JGOFS 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 JGOFS time-series sampling program, and supports development of new instrumentation for hydrographic observations. The objectives of HOT specific to the JGOFS 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 N and P in the upper 200 m of the water column.
- Measure the time-varying concentrations of DIC in the upper water column and estimate the annual air-to-sea CO$_2$ 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-JGOFS web page (hahana.soest.hawaii.edu/hot/ancillary.html).
<table>
<thead>
<tr>
<th>Principal Investigator(s)</th>
<th>Institution</th>
<th>Agency</th>
<th>Project Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claudia Benitez-Nelson</td>
<td>Univ. Hawaii</td>
<td>NSF</td>
<td>$^{234}$Th export</td>
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<tr>
<td>Edward Boyle</td>
<td>MIT</td>
<td>NSF</td>
<td>trace metals</td>
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<tr>
<td>Karin Björkman</td>
<td>Univ. Hawaii</td>
<td>NSF</td>
<td>coupled intensification of N and P cycles in the subtropical North Pacific Ocean</td>
</tr>
<tr>
<td>Charles Keeling</td>
<td>UCSD</td>
<td>NSF</td>
<td>$^{13}$C/$^{12}$C ratio of atmosphere carbon dioxide and oceanic carbon in relation to the global carbon cycle</td>
</tr>
<tr>
<td>Paul Quay</td>
<td>Univ. Washington</td>
<td>NOAA</td>
<td>$^{13}$C/$^{12}$C of dissolved inorganic carbon in the ocean</td>
</tr>
<tr>
<td>Peter le B Williams</td>
<td>Univ. Wales, Bangor</td>
<td>NERC</td>
<td>oxygen flux</td>
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</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-JGOFS web page (hahana.soest.hawaii.edu/hot/hot_jgos).
After consideration of these criteria, we established our primary sampling site at 22° 45' N, 158° W at a location approximately 100 km north of the island of Oahu (Figure 1.1), and generally restrict our monthly sampling activities to a circle with an 10 km radius around this nominal site (Figure 1.2). Station ALOHA is in deep water (4750 m) and is more than one Rossby radius (50 km) away from steep topography associated with the Hawaiian Ridge. We also established a coastal station WSW of the island of Oahu, approximately 10 km off Kahe Point (21° 20.6' N, 158° 16.4' W) in 1500 m of water. Station Kahe serves as a coastal analogue to our deep-water site and the data collected there provide a near-shore time-series for comparison to our primary open ocean site. Station Kahe is also used to test our equipment each month before departing for Station ALOHA, and to orient new personnel at the beginning of each cruise. From January 1997 to October 2000, a physical-biogeochemical mooring was deployed to obtain continuous measurements of various atmospheric and oceanographic parameters. The mooring was located at 22° 28' N, 158° 8' W and was designated as Station HALE-ALOHA. Locations and dates of occupancy of HOT water column and bottom recording stations are available on the HOT-JGOFS 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, 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). The majority of our sampling effort, approximately 60-72 h per standard HOT cruise, is spent at Station ALOHA. 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 thermostalinograph 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. R/V Ka’imikai-o-Kanaloa is outfitted with a similar seawater intake system to which the existing instruments were installed when R/V Moana Wave was retired.

High vertical resolution environmental data are collected with a Sea-Bird CTD having external temperature (T), conductivity (C), dissolved oxygen (DO) and fluorescence 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, 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 samples were collected at, duplicate samples were taken from the rosette. Comparisons with the Go-Flo collected samples showed there was no statistical difference. Starting HOT-119, we 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 300 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 2001. Starting point of deployment indicated by “S”. [Right panels] CTD cast locations during each HOT cruise in 2001. Location numbers correspond to cast numbers. Dashed line indicates the 10 km radius circle defining the station.
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2: continued
Figure 1.2 continued: Due to heavy seas, no sediment traps were deployed on HOT-133.
1.5 Core Measurements, Experiments and Protocols

The suite of core measurements provides a database to validate existing biogeochemical models and to develop improved ones. 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, in situ biological rate experiments, and observations and sample collections from bottom-moored instruments and buoys (Table 1.3). Continuity in the measurement parameters and their quality, rather than continuity in the methods employed, is of greatest interest. Detailed analytical methods are expected to change over time through technical improvements. In addition to the core data, specialized measurements and process-oriented experiments have also been conducted at Station ALOHA (Table 1.3).

Table 1.3: Parameters Measured at Station ALOHA during 2001

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Depth Range (m)</th>
<th>Analytical Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Continuous Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depth (Pressure)</td>
<td>0-4750</td>
<td>Pressure transducer on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Temperature</td>
<td>0-4750</td>
<td>Thermistor on Sea-Bird CTD package</td>
</tr>
<tr>
<td>Conductivity (Salinity)</td>
<td>0-4750</td>
<td>Conductivity sensor on Sea-Bird CTD package, standardization with Guildline AutoSal using Wormley seawater standard</td>
</tr>
<tr>
<td>Dissolved Oxygen</td>
<td>0-4750</td>
<td>YSI or Sea-Bird sensor on Sea-Bird CTD package with Winkler standardization</td>
</tr>
<tr>
<td>Fluorescence (Chloropigment)</td>
<td>0-4750</td>
<td>Sea-Tech flash fluorometer or Sea-Point chlorophyll fluorometer on Sea-Bird CTD package with discrete chlorophyll calibration</td>
</tr>
<tr>
<td><strong>II. Water Column Chemical Measurements</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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>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>-----------------------------</td>
<td>--------</td>
<td>-------------------------------</td>
</tr>
<tr>
<td>Particulate Carbon</td>
<td>0-350</td>
<td>High temperature combustion</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</td>
</tr>
</tbody>
</table>

### III. Biomass Measurements

| Chlorophyll \( a \) and Pheopigments | 0-175 | Fluorometric analysis using 10-AU |
| Chlorophyll \( a, b \) and \( c \) | 0-175 | Fluorometric analysis using TD-700 |
| Pigments                        | 0-175 | HPLC                           |
| Phycoerythrin                   | 0-175 | Fluorometric analysis using TD-700 |
| Adenosine 5′-triphosphate      | 0-350 | Firefly bioluminescence        |
| Bacteria and Cyanobacteria     | 0-175 | Flow cytometry                 |
| Mesozooplankton                | 0-175 | Net tows, elemental analysis   |

### IV. Carbon Assimilation and Particle Flux

<table>
<thead>
<tr>
<th>Primary Production</th>
<th>0-125</th>
<th>“Clean” (^{14})C incubations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon, Nitrogen, Phosphorus</td>
<td>150</td>
<td>Free-floating particle traps</td>
</tr>
<tr>
<td>Particulate Silica</td>
<td>150</td>
<td>Base Hydrolysis</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 thermostalinograph package |
| Fluorometry (Chloropigment) | 3 | Turner Designs 10-AU |

### VII. Optical Measurements

| Incident Irradiance | Surface | LI-COR LI-1000 and Biospherical collector |
| Upwelling radiance and downwelling irradiance | 0-175 | Biospherical Profiling Reflectance Radiometer PRR-600 |
| Downwelling irradiance | 0-3 | Tethered Spectral Radiometer Buoy |

### 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 thirteenth full year of the HOT Program (January-December 2001). During this period, all regular HOT cruises were
conducted using the University of Hawaii research vessel R/V Ka'imikai-o-Kanaloa (Table 1.4). University of Hawaii shipboard technical assistance personnel assisted a total field scientific crew of 47 HOT staff, students and visiting scientists (Table 1.5) in our 2001 field work.

Table 1.4: Chronology of 2001 HOT Cruises

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Ship</th>
<th>Depart</th>
<th>Return</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>R/V KOK</td>
<td>12 February 2001</td>
<td>15 February 2001</td>
</tr>
<tr>
<td>124</td>
<td>R/V KOK</td>
<td>19 March 2001</td>
<td>23 March 2001</td>
</tr>
<tr>
<td>125</td>
<td>R/V KOK</td>
<td>16 April 2001</td>
<td>20 April 2001</td>
</tr>
<tr>
<td>126</td>
<td>R/V KOK</td>
<td>14 May 2001</td>
<td>18 May 2001</td>
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<td>127</td>
<td>R/V KOK</td>
<td>12 June 2001</td>
<td>16 June 2001</td>
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<td>128</td>
<td>R/V KOK</td>
<td>9 July 2001</td>
<td>13 July 2001</td>
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<td>129</td>
<td>R/V KOK</td>
<td>6 August 2001</td>
<td>10 August 2001</td>
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<tr>
<td>130</td>
<td>R/V KOK</td>
<td>30 September 2001</td>
<td>4 October 2001</td>
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<tr>
<td>131</td>
<td>R/V KOK</td>
<td>21 October 2001</td>
<td>26 October 2001</td>
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<td>132</td>
<td>R/V KOK</td>
<td>15 November 2001</td>
<td>19 November 2001</td>
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<tr>
<td>133</td>
<td>R/V KOK</td>
<td>12 December 2001</td>
<td>16 December 2001</td>
</tr>
</tbody>
</table>

Table 1.5: 2001 Cruise Personnel (shaded area = cruise participant)

<table>
<thead>
<tr>
<th>Cruise Participants</th>
<th>122</th>
<th>123</th>
<th>124</th>
<th>125</th>
<th>126</th>
<th>127</th>
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<tbody>
<tr>
<td>Adam-Phillips, Cathrine</td>
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<td>Allen, Colleen</td>
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2.0 SAMPLING PROCEDURES AND ANALYTICAL METHODS

A comprehensive summary of all sampling and analytical methods currently used in the HOT program along with information on measurement accuracy and precision can be found in the “Hawaii Ocean Time-series Program Field and Laboratory Protocols” manual. This document is available on the World Wide Web (hahana.soest.hawaii.edu/hot/protocols/protocols.html). Brief summaries of methods as well as calibration specifications and quality control / quality assurance information for 2001 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,” and is also available on the web (www.soest.hawaii.edu/HOT_WOCE/manual/toc.html).

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-123, 124, 126, 128, 129, 132, and 133. CTD #92859 was used during HOT-122, 125, 127, 130, and 131; this unit was also used in some of the casts during HOT-124, 128, and 129.

CTD casts are made at Stations Kahe and ALOHA during each cruise. A CTD cast to 1000 m is made at Station Kahe. A second cast to 1000 m was conducted at Station Kahe during HOT-128 and 129.

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. During HOT-123 the CTD burst period was not completed due to bad weather and a medical emergency. One WOCE standard cast within 10 m of the bottom is made during each cruise. An additional deep cast was obtained at this Station during all the 2001 cruises except HOT-123, 124, 129, and 133.

Station HALE-ALOHA (site of the bottom moored array) was occupied during all the 2001 HOT cruises except HOT-123. One CTD cast to 1000 m (2000 m during HOT-128) was conducted at this location even when the mooring was not installed during 2001; an additional CTD cast to 25 m was obtained at this Station during HOT-129.

A CTD cast to 2400 m was conducted at Station Kaena during every 2001 cruise except HOT-123, additional shallower CTD casts to 1000 m or less were conducted at this Station during HOT-129, 130 and 131.

CTD casts to 600 m were conducted at eleven additional stations (Stations 9-19) during HOT-122, to survey for an eddy feature identified during the cruise (see Section 4.1).
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 analog 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 2001 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 122, 123, 124, 126, 132, and 133 were conducted under rough sea conditions, with heavy ship rolling during some of the casts, causing large vertical velocity fluctuation of the CTD package. The acceleration cutoff value had to be increased to between 0.55 and 0.7 m s$^{-2}$ 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. Due to intermittent problems with the internal power supply of CTD #91361 during cruises HOT-126 and 128, some of the casts had data glitches that were flagged. Casts 3, 7 and 16 from station 2 had glitches in salinity and oxygen during HOT-126; cast 1 at stations 1 and 2 had temperature, salinity and oxygen glitches during HOT-128.

Temperature is reported in the ITS-90 scale. Salinity and all derived units were calculated using the UNESCO (1981) routines; salinity is reported in the practical salinity scale (PSS-78). Oxygen is reported in $\mu$mol kg$^{-1}$.

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 in average at the Northwest Regional Calibration Center and at the Scripps Institute of
Oceanography. The latest calibrations were conducted at the Scripps Institute of Oceanography in April 1999 and May 2001.

### 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 (primary CTD #91361), and #51412 (backup 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.

Pressure transducer #75434 was used during cruises HOT-123, 124, 126, 128, 129, 132, and 133. Pressure transducer #51412 was used during HOT-122, 125, 127, 130, and 131; this sensor was also used in some of the casts during HOT-124, 128, and 129. No correction was applied to the pressure offset at 0 dbar during data collection, except for casts conducted with sensor #51412 after June 2001, in which a 1.14 dbar offset correction was applied (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 after August 2001 has been removed in this plot for comparison with previous data). The before-cast pressures for sensor #75434 are about 0.3 dbar higher than the 0 dbar offset from the 2001-2002 calibrations. This is because prior to the pressure tests the CTD is powered on 24 hours for full stabilization, while the on-deck pressures are taken only about 10 min after the CTD is powered on. Also, the mean difference between before-cast and an after-cast on-deck pressure is about 0.5 dbar, 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. A linear pressure dependent offset is applied during data collection for sensor #51412, to correct for the 0-4500 dbar offset.

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Table 2.1: CTD Pressure Calibrations against transfer standard. Offset at 0 dbar for tests before September 1998 are not available (see text). Units are decibars.

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<th>Hysteresis</th>
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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 122-133. Error bars are one standard deviation from the mean. Cruise numbers are shown below the upper X-axis.
2.1.2.2 Temperature

Three Sea-Bird SBE-3-Plus temperature transducers #2242, #2700, and #2454 were used in 2001 and were calibrated at Sea-Bird after every cruise except HOT-130 because of the short time before the following cruise. SBE-3-02/F transducers #1591, #1416 and #741 were backup sensors also calibrated after every cruise except HOT-130. In addition, temperature transducers #1416 and #1591 were not calibrated in July. 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 2000 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):

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

Table 2.2: Calibration coefficients for Sea-Bird temperature sensors. RMS residuals from calibration give an indication of quality of the calibration. Sensors #2045, #1496, #1392, and #2078 were used by the thermosalinograph (Section 2.2).

<table>
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<th>SN</th>
<th>Date</th>
<th>f0</th>
<th>a</th>
<th>b</th>
<th>c</th>
<th>d</th>
<th>RMS (m°C)</th>
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22
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 2001 was less
than 1.2 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 2001 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 2001 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 #2242

This sensor was used during all the 2001 HOT cruises. The calibrations from December
1996 through January 2002 show that the sensor had a significant drift increase starting in
January 2001. Our records do not show anything that would justify this drift change. This
behavior could be a normal sensor behavior due to aging (Nordeen Larson, personal
communication, 2002). The calibrations from January 2001 through December 2001 were used
to estimate a sensor drift of 3.72 x 10^{-6} °C day^{-1} with an intercept of −7.2 x 10^{-8} °C and a RMS
residual of 7.02 x 10^{-5} °C. For comparison, the drift before January 2001 was −1.7 x 10^{-7} °C
day^{-1}. The 2001 drift was used to obtain the correction for cruises HOT-122 through HOT-133.
When corrected for linear drift to 30 June 2001 (the midpoint of the cruise dates), the 27 January
2001 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of
calibrations obtained in 2001 (also corrected for linear drift to 30 June 2001). The deviation was
4.3 x 10^{-6} °C with less than 0.2 x 10^{-4} °C range of variation. The set of all calibrations had
deviations in the range ± 3 x 10^{-4} °C. Using this calibration as a baseline, drift corrections were
obtained and applied to the 2001 HOT cruise data (Table 2.3).
Sensor #2454

The calibrations from March 1999 through January 2002 were used to obtain a drift of \(-1.37 \times 10^{-6} \, ^\circ C \, day^{-1}\) with an intercept of \(1.74 \times 10^{-4} \, ^\circ C\) and a RMS residual of \(1.47 \times 10^{-4} \, ^\circ C\), and was used to obtain the drift correction for cruises HOT-122, and HOT-128 through 133. When corrected for linear drift to 20 October 2001, the 27 June 2001 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 20 October 2001). Drift corrections were obtained using this calibration as a baseline. The deviation was \(8.0 \times 10^{-6} \, ^\circ C\) with less than \(0.2 \times 10^{-4} \, ^\circ C\) range of variation. The set of all calibrations had deviations in the range ± \(2.5 \times 10^{-4} \, ^\circ C\). The resulting drift corrections for each cruise were insignificant (Table 2.3).

Sensor #2700

The calibrations from July 2000 through January 2002 were used to estimate a sensor drift of \(-2.14 \times 10^{-6} \, ^\circ C \, day^{-1}\) with an intercept of \(1.54 \times 10^{-4} \, ^\circ C\) and a RMS residual of \(9.84 \times 10^{-5} \, ^\circ C\). This drift was used to obtain the correction for cruises HOT-123 through 127. When corrected for linear drift on 18 April 2001 (the midpoint of the cruise dates), the 30 March 2001 calibration gave the smallest deviation in the 0-5 °C temperature range from the set of all calibrations (also corrected for linear drift to 18 April 2001. Using this calibration as baseline, drift corrections were obtained. The deviation was \(8.4 \times 10^{-6} \, ^\circ C\) with less than \(0.3 \times 10^{-4} \, ^\circ C\) range of variation. The set of all calibrations had deviations in the range ± \(2.5 \times 10^{-4} \, ^\circ C\). The resulting drift corrections for each cruise were insignificant (Table 2.3).

Sensor #1416

This sensor was not used during 2001. The calibrations from April 1996 through January 2002 yielded a linear drift of \(2.43 \times 10^{-6} \, ^\circ C \, day^{-1}\), with an intercept of \(-1.56 \times 10^{-4} \, ^\circ C\), and \(1.96 \times 10^{-4} \, ^\circ C\) RMS residuals. This sensor has maintained a constant and uninterrupted drift for a long time compared to our other sensors.

Sensor #1591

This sensor was not used during 2001. The calibrations from June 1999 through January 2002 yielded a sensor drift of \(3.54 \times 10^{-6} \, ^\circ C \, day^{-1}\) with a \(-3.91 \times 10^{-4} \, ^\circ C\) intercept and \(3.71 \times 10^{-4} \, ^\circ C\) RMS residual.

Sensor #741

This sensor was not used during 2001. The calibrations from June 1999 through January 2002 show an apparent offset after the January 2001 calibration, and again in November 2001. The overall sensor drift was \(1.01 \times 10^{-6} \, ^\circ C \, day^{-1}\) with a \(1.2 \times 10^{-4} \, ^\circ C\) intercept and \(3.8 \times 10^{-4} \, ^\circ C\) RMS residual.
Table 2.3: Temperature (T) and Conductivity (C) sensor corrections including the thermal inertia parameter (\( \alpha \)). Dual temperature and conductivity sensors were used in all cruises. The last column indicates which T-C sensor pair’s data is reported.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>T sensor #</th>
<th>T Correction (°C)</th>
<th>C sensor #</th>
<th>( \alpha )</th>
<th>Data reported</th>
</tr>
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<tbody>
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<td>HOT-122</td>
<td>2454</td>
<td>0.000220</td>
<td>2218</td>
<td>0.028</td>
<td>All casts</td>
</tr>
<tr>
<td>HOT-122</td>
<td>2242</td>
<td>-0.000037</td>
<td>1336</td>
<td>0.028</td>
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</tr>
<tr>
<td>HOT-123</td>
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<td>0.000094</td>
<td>2218</td>
<td>0.028</td>
<td>All casts</td>
</tr>
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2.1.2.3 Conductivity

Four conductivity sensors were used during the 2001 cruises, #2218, #2541, #1336, and #679. 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 \( \alpha \) parameter used for each cruise.

Procedures for preliminary screening of bottle samples and empirical calibration of the conductivity cell are described in Tupas et al. (1993, 1994a). For cruises HOT-122 through -133,
The standard deviation cutoff values for screening of bottle salinity samples were: 0.0036 (0-150 dbar), 0.0048 (151-500 dbar), 0.0021 (501-1050 dbar), and 0.0012 (1051-5000 dbar).

The conductivity calibration coefficients \((b_0, b_1, b_2)\) derived from the least squares fit \((\Delta C = b_0 + b_1C + b_2C^2)\) to the CTD-bottle conductivity differences \((\Delta C)\) as a function of conductivity \((C)\) are given in Table 2.4. 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

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<th>(b_2)</th>
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</tr>
<tr>
<td>HOT-126</td>
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<td>-0.000064</td>
<td></td>
</tr>
<tr>
<td>HOT-127</td>
<td>2218</td>
<td>0.000868</td>
<td>-0.000228</td>
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</tr>
<tr>
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<td>0.000397</td>
<td>-0.000082</td>
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</tr>
<tr>
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<td>0.005646</td>
<td>-0.002531</td>
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</tr>
<tr>
<td>HOT-128</td>
<td>2541</td>
<td>0.000385</td>
<td>-0.000037</td>
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</tr>
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<td>HOT-129</td>
<td>2541</td>
<td>0.000398</td>
<td>-0.000054</td>
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</tr>
<tr>
<td>HOT-129</td>
<td>679</td>
<td>0.000989</td>
<td>-0.000429</td>
<td></td>
</tr>
<tr>
<td>HOT-130</td>
<td>2218</td>
<td>0.001034</td>
<td>-0.000314</td>
<td></td>
</tr>
<tr>
<td>HOT-130</td>
<td>2541</td>
<td>0.000450</td>
<td>-0.000125</td>
<td></td>
</tr>
<tr>
<td>HOT-131</td>
<td>2218</td>
<td>0.005778</td>
<td>-0.002654</td>
<td>0.000277</td>
</tr>
<tr>
<td>HOT-132</td>
<td>2218</td>
<td>0.000918</td>
<td>-0.000257</td>
<td></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-122</td>
<td>2</td>
<td>1</td>
<td>-0.000077</td>
<td></td>
</tr>
<tr>
<td>HOT-123</td>
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<td>2</td>
<td>0.000089</td>
<td></td>
</tr>
<tr>
<td>HOT-124</td>
<td>2</td>
<td>2</td>
<td>-0.000064</td>
<td></td>
</tr>
<tr>
<td>HOT-127</td>
<td>2</td>
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<td>0.000107</td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Station</th>
<th>Cast</th>
<th>0-4800 dbar</th>
<th>500-4800 dbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-122</td>
<td>2218</td>
<td>0.0001</td>
<td>0.0023</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-122</td>
<td>1336</td>
<td>0.0001</td>
<td>0.0021</td>
<td>-0.0001</td>
</tr>
<tr>
<td>HOT-123</td>
<td>2218</td>
<td>-0.0002</td>
<td>0.0024</td>
<td>0.0000</td>
</tr>
<tr>
<td>HOT-123</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0022</td>
<td>0.0003</td>
</tr>
<tr>
<td>HOT-124</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0024</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-124</td>
<td>2541</td>
<td>0.0001</td>
<td>0.0019</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-125</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0018</td>
<td>0.0005</td>
</tr>
<tr>
<td>HOT-125</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0018</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-126</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0019</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-126</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0017</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-127</td>
<td>2218</td>
<td>-0.0001</td>
<td>0.0021</td>
<td>0.0003</td>
</tr>
<tr>
<td>HOT-127</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0016</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-128</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0022</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-128</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0017</td>
<td>0.0003</td>
</tr>
<tr>
<td>HOT-129</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0013</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-129</td>
<td>679</td>
<td>-0.0000</td>
<td>0.0018</td>
<td>-0.0000</td>
</tr>
<tr>
<td>HOT-130</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0019</td>
<td>0.0005</td>
</tr>
<tr>
<td>HOT-130</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0015</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-131</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0015</td>
<td>0.0001</td>
</tr>
<tr>
<td>HOT-131</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0014</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-132</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0014</td>
<td>0.0004</td>
</tr>
<tr>
<td>HOT-132</td>
<td>2541</td>
<td>0.0000</td>
<td>0.0013</td>
<td>0.0002</td>
</tr>
<tr>
<td>HOT-133</td>
<td>2218</td>
<td>0.0000</td>
<td>0.0014</td>
<td>0.0005</td>
</tr>
<tr>
<td>HOT-133</td>
<td>2541</td>
<td>0.0001</td>
<td>0.0012</td>
<td>0.0003</td>
</tr>
</tbody>
</table>
Figure 2.2: Difference between calibrated CTD salinities and bottle salinities for each cruise and all casts at Station ALOHA in 2001.
2.1.2.4 Oxygen

During the 2001 cruises two developmental versions (#43004 and #43045), and three production line versions (#43019, #43020 and #43166) of the Sea-Bird SBE-43 oxygen sensor were used. Sensors #43019 and #43020 belong to STAG. Sensors #43004 and #43045 were calibrated at Sea-Bird before each cruise. Sensors #43019 and #43020 were calibrated in April 2001, and sensor #43020 was repaired and calibrated again in November 2001 after failing during HOT-129. Sensor #43166 was acquired in November 2001, but failed during HOT-133 and was repaired and calibrated at Sea-Bird in January 2002.

Two YSI Inc. probes (#13434 and #13251) were also used during HOT cruises; these sensors were calibrated in February 2001 at Sea-Bird. Sensor #13434 failed during HOT-132 and was retired of use. The regular maintenance procedure for the YSI sensors includes inspection of their electrolyte level and membrane before each cruise. Sensor #13251 had its membrane replaced during HOT-126. Both sensors had their membrane and electrolyte replaced prior to HOT-130. The history of these sensors is documented in Santiago-Mandujano et al. (2002, 2001, 1999), Tupas et al. (1995, 1997, 1998) and Karl et al. (1996).

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. Three sets of parameters were usually obtained per HOT cruise, corresponding to the casts at Stations 1, 2 and 8. The calibration procedure for the Sea-Bird SBE-43 sensors is different from that for the YSI sensors because these sensors do internal temperature compensation and do not output the oxygen probe internal temperature data as in the case of the YSI sensors (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-122</td>
<td>13251</td>
<td>0.02</td>
<td>0.82</td>
</tr>
<tr>
<td>HOT-123</td>
<td>13251</td>
<td>0.01</td>
<td>0.94</td>
</tr>
<tr>
<td>HOT-124</td>
<td>43004</td>
<td>0.01</td>
<td>1.25</td>
</tr>
<tr>
<td>HOT-125</td>
<td>43004</td>
<td>0.01</td>
<td>1.32</td>
</tr>
<tr>
<td>HOT-126</td>
<td>43004</td>
<td>0.01</td>
<td>1.00</td>
</tr>
<tr>
<td>HOT-127</td>
<td>43004</td>
<td>0.01</td>
<td>0.74</td>
</tr>
<tr>
<td>HOT-128</td>
<td>43004</td>
<td>0.00</td>
<td>0.99</td>
</tr>
<tr>
<td>HOT-129</td>
<td>43045</td>
<td>0.01</td>
<td>0.96</td>
</tr>
<tr>
<td>HOT-130</td>
<td>43019</td>
<td>0.01</td>
<td>0.99</td>
</tr>
<tr>
<td>HOT-131</td>
<td>43045</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>HOT-132</td>
<td>43045</td>
<td>0.01</td>
<td>0.87</td>
</tr>
<tr>
<td>HOT-133</td>
<td>43020</td>
<td>0.01</td>
<td>0.68</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-122</td>
<td>13251</td>
<td>0.11</td>
<td>0.86</td>
<td>0.06</td>
<td>0.74</td>
</tr>
<tr>
<td>HOT-123</td>
<td>13251</td>
<td>0.03</td>
<td>1.06</td>
<td>0.22</td>
<td>0.95</td>
</tr>
<tr>
<td>HOT-124</td>
<td>43004</td>
<td>0.17</td>
<td>0.93</td>
<td>0.00</td>
<td>0.94</td>
</tr>
<tr>
<td>HOT-125</td>
<td>43004</td>
<td>0.11</td>
<td>1.22</td>
<td>0.08</td>
<td>1.32</td>
</tr>
<tr>
<td>HOT-126</td>
<td>43004</td>
<td>0.09</td>
<td>0.89</td>
<td>0.03</td>
<td>0.80</td>
</tr>
<tr>
<td>HOT-127</td>
<td>43004</td>
<td>0.07</td>
<td>0.87</td>
<td>0.03</td>
<td>0.72</td>
</tr>
<tr>
<td>HOT-128</td>
<td>43004</td>
<td>0.02</td>
<td>1.05</td>
<td>-0.06</td>
<td>1.07</td>
</tr>
<tr>
<td>HOT-129</td>
<td>43019</td>
<td>0.01</td>
<td>0.78</td>
<td>-0.02</td>
<td>0.68</td>
</tr>
<tr>
<td>HOT-130</td>
<td>43019</td>
<td>0.11</td>
<td>1.05</td>
<td>0.09</td>
<td>0.97</td>
</tr>
<tr>
<td>HOT-131</td>
<td>43045</td>
<td>0.07</td>
<td>0.89</td>
<td>0.05</td>
<td>0.81</td>
</tr>
<tr>
<td>HOT-132</td>
<td>43045</td>
<td>0.04</td>
<td>0.79</td>
<td>0.05</td>
<td>0.78</td>
</tr>
<tr>
<td>HOT-133</td>
<td>43020</td>
<td>0.03</td>
<td>0.86</td>
<td>-0.05</td>
<td>0.72</td>
</tr>
</tbody>
</table>
Table 2.7c: CTD-Bottle dissolved oxygen at Station HALE-ALOHA (µmol kg\(^{-1}\))

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-122</td>
<td>13251</td>
<td>0.04</td>
<td>1.48</td>
</tr>
<tr>
<td>HOT-124</td>
<td>43004</td>
<td>0.01</td>
<td>0.87</td>
</tr>
<tr>
<td>HOT-125</td>
<td>43004</td>
<td>0.01</td>
<td>0.92</td>
</tr>
<tr>
<td>HOT-126</td>
<td>43004</td>
<td>0.02</td>
<td>0.98</td>
</tr>
<tr>
<td>HOT-127</td>
<td>43004</td>
<td>0.00</td>
<td>0.98</td>
</tr>
<tr>
<td>HOT-128</td>
<td>43004</td>
<td>-0.01</td>
<td>1.18</td>
</tr>
<tr>
<td>HOT-129</td>
<td>43019</td>
<td>0.00</td>
<td>0.85</td>
</tr>
<tr>
<td>HOT-130</td>
<td>43019</td>
<td>0.00</td>
<td>1.49</td>
</tr>
<tr>
<td>HOT-131</td>
<td>43045</td>
<td>0.01</td>
<td>0.62</td>
</tr>
<tr>
<td>HOT-132</td>
<td>43045</td>
<td>0.01</td>
<td>1.23</td>
</tr>
<tr>
<td>HOT-133</td>
<td>43020</td>
<td>0.00</td>
<td>0.41</td>
</tr>
</tbody>
</table>

2.1.2.5 Fluorescence (Chloropigment)

Fluorescence was measured with a Sea-Tech Model ST0250 flash fluorometer (#32) up until HOT-130, then with a Sea-Point chlorophyll fluorometer (#2440 and #2441) from HOT-131 onwards. 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). Samples from a large batch of “secondary standard” (substandard) seawater were measured after every 12 to 24 bottle samples to detect drift in the salinometer for each cruise. Standard deviations of the secondary standard measurements were less than \(\pm 0.001\) 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 #23 through #27 were prepared on November 1, 2000, March 27, 2001, June 16, 2001, October 5, 2001 and November 19, 2001 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-122</td>
<td>34.4695 ± 0.0004</td>
<td>29</td>
<td>23</td>
<td>p136</td>
</tr>
<tr>
<td>HOT-123</td>
<td>34.4680 ± 0.0003</td>
<td>22</td>
<td>23</td>
<td>p136</td>
</tr>
<tr>
<td>HOT-124</td>
<td>34.4728 ± 0.0003</td>
<td>39</td>
<td>24</td>
<td>p136</td>
</tr>
<tr>
<td>HOT-125</td>
<td>34.4731 ± 0.0004</td>
<td>44</td>
<td>24</td>
<td>p136</td>
</tr>
<tr>
<td>HOT-126</td>
<td>34.4725 ± 0.0003</td>
<td>46</td>
<td>24</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-127</td>
<td>34.4746 ± 0.0004</td>
<td>45</td>
<td>25</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-128</td>
<td>34.4735 ± 0.0005</td>
<td>54</td>
<td>25</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-129</td>
<td>34.4723 ± 0.0004</td>
<td>61</td>
<td>25</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-130</td>
<td>34.4779 ± 0.0005</td>
<td>67</td>
<td>26</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-131</td>
<td>34.4775 ± 0.0004</td>
<td>53</td>
<td>26</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-132</td>
<td>34.4730 ± 0.0004</td>
<td>62</td>
<td>27</td>
<td>p138</td>
</tr>
<tr>
<td>HOT-133</td>
<td>34.4712 ± 0.0004</td>
<td>34</td>
<td>27</td>
<td>p138</td>
</tr>
</tbody>
</table>

2.2 Thermosalinograph

2.2.1 Data acquisition

A SBE-21 Seacat thermosalinograph system was used aboard R/V Ka'imikai-o-Kanaloa for the HOT-122 through HOT-133 cruises.

Sea-Bird thermosalinograph sensor #2045 (comprised of one temperature and one conductivity sensor) was used for HOT-122 through HOT-127. Cruises HOT-128 through HOT-133, used Seacat thermosalinograph sensor #1392 (also comprised of one temperature and one conductivity sensor). The thermosalinograph is installed in a pumped intake line in the hull of the R/V Ka'imikai-o-Kanaloa with an intake depth of about 3 m. This thermosalinograph is used to calculate salinity using internal sensors’ temperature and conductivity, and the intake flow pump’s pressure (10 dbar). Conductivities are calibrated using bottle salinity samples periodically taken (every 4 hours) from the intake line. Near the start of the intake line, a Sea-Bird remote temperature sensor, installed in a sea chest in the bow of the ship, recorded temperature data. This location allows for relatively undisturbed water to enter the thermosalinograph. Sea-Bird remote or external temperature sensor #2078 was used for HOT-122 through HOT-127 and HOT-129 through HOT-133. HOT-128 used Sea-Bird external temperature sensor #1496. Data were obtained 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 temperature sensors (#1392 and #2045) and external temperature sensors (#1496 and #2078) have been calibrated at Sea-Bird (calibration coefficients in Table 2.2). Since these sensors are the same type as used for the CTD measurements, the same procedure for drift estimation was followed (see Section 2.1.2.2).

A temperature drift rate of $-8.27 \times 10^{-7} \degree C \text{ day}^{-1}$ was determined for internal temperature sensor #1392 using the 29 August 1994, 13 October 1995, 20 August 1997, 28 August 1997, 18 November 1998, 27 January 2000 and 27 January 2002 calibrations. The calibration from 17 January 2001 was an outlier and not used in calculating temperature sensor drift. Temperatures were calculated with the 27 January 2002 baseline calibration. Drift corrections were not applied to the data for this temperature sensor, as they are very small and inconsequential.

For internal temperature sensor #2045, a drift rate of $5.51 \times 10^{-7} \degree C \text{ day}^{-1}$ was determined using the 11 October 1995, 30 July 1996, 28 July 1998, 10 August 1999, 8 September 2000, and 30 June 2001 calibrations. Temperatures were calculated with the 8 September 2000 baseline calibration. Drift corrections were not applied to the data for this temperature sensor, as they are very small and inconsequential.

A drift rate of $2.88 \times 10^{-6} \degree C \text{ day}^{-1}$ was determined using the 2 November 1993, 18 January 1996, 16 July 1998, 13 January 2000, 18 January 2001, 3 August 2001, and 6 April 2002 calibrations for remote temperature sensor #1496. Temperature sensor #1496 was only used for HOT-128 and failed during the cruise. An offset was applied to the internal temperature data to estimate external temperature. The offset, $-0.065 \degree C$, was calculated from the mean difference between the internal and external temperature sensors during HOT-127 and HOT-129.

For remote temperature sensor #2078 a drift rate of $3.99 \times 10^{-7} \degree C \text{ day}^{-1}$ was determined using the 12 August 1999, 8 September 2000, 30 June 2001, and 30 January 2002 calibrations. Temperatures for HOT-122-127 were calculated with the 8 of August 2000 baseline calibration, and temperatures for HOT-129-133 were calculated with the 30 of June 2001 baseline calibration. Drift corrections were not applied to the data for this temperature sensor, as they are very small and inconsequential.

2.2.2.1.2 Conductivity

Sea-Bird conductivity sensor #2045 was used to collect thermsalinograph conductivity data for HOT-122 through HOT-127. Conductivity sensor #1392 was used for HOT-128 through HOT-133. For sensor #2045, all conductivity data were nominally calibrated with coefficients obtained at Sea-Bird on 8 September 2000. For sensor #1392, all conductivity data were nominally calibrated with coefficients obtained at Sea-Bird on 17 January 2001. However,
all the final salinity data reported here were calibrated against bottle data as explained below (Section 2.2.2.3).

2.2.2.2 Processing

The thermosalinograph data were screened for gross errors with upper and lower bounds of 35 °C and 18 °C for temperature and 6 and 3 Siemens m$^{-1}$ for conductivity. There were 82 gross errors detected during the 2001 cruises. Despite the small number of gross errors, some data have been deemed suspicious or bad. These could be ascribed to factors such as biological fouling of the thermosalinograph, air bubbles in the thermosalinograph system, etc. Hence, a quality control system has been established so that each temperature and salinity point is given a flag to determine whether the data are good, suspect or bad. A 5-point running median filter was used to detect one or two point temperature and conductivity glitches in the thermosalinograph data. Glitches in temperature and conductivity detected by the 5-point median filter were immediately replaced by the median. Threshold values of 0.3 °C for temperature and 0.1 Siemens m$^{-1}$ for conductivity were used for the median filter. No more than a few points were replaced after running the median filter. A 3-point triangular running mean filter was used to smooth the temperature and conductivity data from all the cruises after they had gone through glitch detection. A visual inspection of the temperature and conductivity record was also done to flag suspect and bad data.

For the 2001 HOT cruises, the number of thermosalinograph data points flagged as suspicious or bad per cruise ranged from zero (HOT-126) to 17,835 (HOT-133), with the majority of the flags applied to the conductivity data. Most sections of flagged data were relatively small and were associated with bottle glitches (data spikes during bottle sampling due to a defective draining pump) or with air bubbles entering the thermosalinograph plumbing during transit. HOT-123, HOT-124, HOT-131 and HOT-133 contained larger sections of flagged data attributed to rough seas and high winds during transit between Station Kahe and Station ALOHA. During HOT-133, in particular, strong winds and rough seas affected the thermosalinograph data during the first two days of the cruise. HOT-123 was also affected by strong winds and rough seas, and, in addition, a medical emergency arose during the cruise that required the research vessel to transit from Station ALOHA to Barbers Point and back again to Station ALOHA. The flagged thermosalinograph data from HOT-123 were mostly during the transit periods. A malfunctioning external temperature sensor during HOT-128 resulted in the entire range of temperature data initially being flagged as bad for that cruise. External temperatures for HOT-128 were later estimated by applying an offset to the internal temperature data (see Section 2.2.2.1.1). All the estimated external temperature data were flagged as interpolated.

An estimate of the noise in the thermosalinograph data was performed to evaluate the quality of the data. A 101-point running mean (about 17 min at 10 sec sampling) 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 near-constant salinity or temperature periods were included in the estimates to avoid large residuals resulting in sections of large variability. Noise estimates were obtained for cruises HOT-122 through -133 (Table 2.9).
Table 2.9: Thermosalinograph data noise estimates during HOT cruises.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Noise estimate</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Salinity</td>
<td>Temperature (°C)</td>
<td></td>
</tr>
<tr>
<td>HOT-122</td>
<td>0.0013</td>
<td>0.0054</td>
<td></td>
</tr>
<tr>
<td>HOT-123</td>
<td>0.0025</td>
<td>0.0039</td>
<td></td>
</tr>
<tr>
<td>HOT-124</td>
<td>0.0015</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>HOT-125</td>
<td>0.0013</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>HOT-126</td>
<td>0.0022</td>
<td>0.0057</td>
<td></td>
</tr>
<tr>
<td>HOT-127</td>
<td>0.0013</td>
<td>0.0047</td>
<td></td>
</tr>
<tr>
<td>HOT-128</td>
<td>0.0012</td>
<td>N/A*</td>
<td></td>
</tr>
<tr>
<td>HOT-129</td>
<td>0.0013</td>
<td>0.0047</td>
<td></td>
</tr>
<tr>
<td>HOT-130</td>
<td>0.0019</td>
<td>0.0057</td>
<td></td>
</tr>
<tr>
<td>HOT-131</td>
<td>0.0012</td>
<td>0.0048</td>
<td></td>
</tr>
<tr>
<td>HOT-132</td>
<td>0.0010</td>
<td>0.0058</td>
<td></td>
</tr>
<tr>
<td>HOT-133</td>
<td>0.0016</td>
<td>0.0036</td>
<td></td>
</tr>
</tbody>
</table>

* Temperature sensor failed

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.

For R/V Ka‘imikai-o-Kanaloa, the thermosalinograph used to calculate salinity was located immediately next to the bottle sampling area. Thus, thermosalinograph data were extracted within ±15 seconds around the sample time.

As in previously reported cruises (Tupas et al. 1997) a cubic spline was fit to the time-series of the differences between the bottle conductivity and the thermosalinograph conductivity separately for all the 2001 cruises. The correction of the thermosalinograph conductivities was obtained from this fit. Salinity was calculated using these corrected conductivities, thermosalinograph temperatures and a pressure of 10 dbar. The mean values for the salinity bottle minus final calibrated thermosalinograph were less than ±3 x 10^-5 for each cruise.

Table 2.10 gives the standard deviation for the salinity bottle minus final calibrated thermosalinograph values for all the 2001 cruises.
Table 2.10: Bottle-Thermosalinograph salinity comparison during the 2001 HOT cruises.

<table>
<thead>
<tr>
<th>Cruise</th>
<th>Sensor #</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>HOT-122</td>
<td>2045</td>
<td>0.0037</td>
</tr>
<tr>
<td>HOT-123</td>
<td>2045</td>
<td>0.0075</td>
</tr>
<tr>
<td>HOT-124</td>
<td>2045</td>
<td>0.0054</td>
</tr>
<tr>
<td>HOT-125</td>
<td>2045</td>
<td>0.0043</td>
</tr>
<tr>
<td>HOT-126</td>
<td>2045</td>
<td>0.0040</td>
</tr>
<tr>
<td>HOT-127</td>
<td>2045</td>
<td>0.0026</td>
</tr>
<tr>
<td>HOT-128</td>
<td>1392</td>
<td>0.0034</td>
</tr>
<tr>
<td>HOT-129</td>
<td>1392</td>
<td>0.0021</td>
</tr>
<tr>
<td>HOT-130</td>
<td>1392</td>
<td>0.0021</td>
</tr>
<tr>
<td>HOT-131</td>
<td>1392</td>
<td>0.0017</td>
</tr>
<tr>
<td>HOT-132</td>
<td>1392</td>
<td>0.0014</td>
</tr>
<tr>
<td>HOT-133</td>
<td>1392</td>
<td>0.0011</td>
</tr>
</tbody>
</table>

2.2.2.4 Comparison with CTD Data

The calibrated thermosalinograph salinity data collected during CTD casts were compared with the downcast CTD salinity at 4 dbar as an additional quality control. This procedure was conducted in the same manner as previously reported HOT cruises (Tupas et al. 1997). The thermosalinograph data were averaged using data sampled one minute after the acquisition time of the CTD sample. Mean temperature comparisons with the CTD were smaller than ±0.01 °C for all cruises. Mean salinity comparisons with the CTD were less than ±0.007 psu for all 2001 HOT cruises.

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 from the anemometer on the R/V Ka‘imikai-o-Kanaloa, recorded at 5-min intervals were also available.

Meteorological observations were also obtained every 4 hours by the ship's officers on the bridge of the R/V Ka‘imikai-o-Kanaloa throughout each cruise.

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. Bad data points were often replaced with the bridge data. Outliers in the shipboard pressure, air temperature, SST, and wind observations were detected by comparison with the buoy data.
Comparisons between the near-surface CTD temperatures and the bucket temperatures indicated high bucket temperatures during cruises HOT-128 through 132, probably due to a faulty bucket thermometer. Corrections were obtained by comparing the CTD temperatures with bucket temperatures taken before each cast. Correction offsets of 0.5, 0.5, 0.5, 0.52, and 0.6 °C were subtracted to the bucket temperatures for each respective cruise.

2.4 ADCP Measurements

Upper ocean currents were measured on all twelve HOT 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. 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, Kaena and HALE-ALOHA, water samples for chemical analyses were collected from discrete depths using 12 liter PVC bottles with teflon 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 2001.

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 concentration 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 2.12. The pooled annual mean CV of our oxygen analyses in 2001 was 0.15 %. It was calculated by averaging the mean CV of N-triplicate samples on each cruise. Oxygen concentrations measured over the 13 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). These results indicate that analytical consistency has been maintained over the past 13 years of the HOT program.

<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>122</td>
<td></td>
<td>0.07</td>
<td>0.14</td>
<td>8</td>
</tr>
<tr>
<td>123</td>
<td></td>
<td>0.11</td>
<td>0.19</td>
<td>8</td>
</tr>
<tr>
<td>124</td>
<td></td>
<td>0.20</td>
<td>0.41</td>
<td>9</td>
</tr>
<tr>
<td>125</td>
<td></td>
<td>0.21</td>
<td>0.41</td>
<td>11</td>
</tr>
<tr>
<td>126</td>
<td></td>
<td>0.15</td>
<td>0.30</td>
<td>11</td>
</tr>
<tr>
<td>127</td>
<td></td>
<td>0.15</td>
<td>0.27</td>
<td>10</td>
</tr>
<tr>
<td>128</td>
<td></td>
<td>0.14</td>
<td>0.26</td>
<td>10</td>
</tr>
<tr>
<td>129</td>
<td></td>
<td>0.09</td>
<td>0.18</td>
<td>9</td>
</tr>
<tr>
<td>130</td>
<td></td>
<td>0.13</td>
<td>0.25</td>
<td>9</td>
</tr>
<tr>
<td>131</td>
<td></td>
<td>0.19</td>
<td>0.37</td>
<td>9</td>
</tr>
<tr>
<td>132</td>
<td></td>
<td>0.12</td>
<td>0.22</td>
<td>9</td>
</tr>
<tr>
<td>133</td>
<td></td>
<td>0.25</td>
<td>0.42</td>
<td>10</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td></td>
<td><strong>0.15</strong></td>
<td><strong>0.28</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>
Figure 2.3: [Upper panel] Difference between sample temperature at the time of sample collection and potential temperature calculated from \textit{in situ} temperature at the time of bottle trip. [Lower panel] Difference in oxygen concentration corrected for temperatures measured at the time of sample collection and potential temperature calculated from \textit{in situ} temperature.
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 2001 was 0.06 % (Table 2.13). 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 2001 was 0.25 % (Table 2.13). The accuracy of DIC and alkalinity measurements was established with certified reference materials (CRMs) obtained from Andrew Dickson at Scripps Institution of Oceanography.

Table 2.13: Precision of DIC and Total Alkalinity analyses during 2001

<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>122</td>
<td>0.07</td>
<td>1.51</td>
</tr>
<tr>
<td>123</td>
<td>0.09</td>
<td>1.81</td>
</tr>
<tr>
<td>124</td>
<td>0.03</td>
<td>0.71</td>
</tr>
<tr>
<td>125</td>
<td>0.05</td>
<td>1.09</td>
</tr>
<tr>
<td>126</td>
<td>0.01</td>
<td>0.27</td>
</tr>
<tr>
<td>127</td>
<td>0.06</td>
<td>1.37</td>
</tr>
<tr>
<td>128</td>
<td>0.08</td>
<td>1.69</td>
</tr>
<tr>
<td>129</td>
<td>0.06</td>
<td>1.35</td>
</tr>
<tr>
<td>130</td>
<td>0.07</td>
<td>1.45</td>
</tr>
<tr>
<td>131</td>
<td>0.15</td>
<td>3.29</td>
</tr>
<tr>
<td>132</td>
<td>0.06</td>
<td>1.32</td>
</tr>
<tr>
<td>133</td>
<td>0.02</td>
<td>0.49</td>
</tr>
<tr>
<td>Mean</td>
<td>0.06</td>
<td>1.36</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 2000 from duplicate analyses are given in Table 2.14. Figures 2.4-2.5 show the mean and 95% confidence limits of nutrient concentrations measured at three potential density horizons for the first 12 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 2.14: Precision of Dissolved inorganic nutrient analyses during 2000

<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>111</td>
<td>0.18</td>
<td>0.032</td>
<td>8</td>
</tr>
<tr>
<td>112</td>
<td>0.21</td>
<td>0.063</td>
<td>9</td>
</tr>
<tr>
<td>113</td>
<td>0.31</td>
<td>0.068</td>
<td>9</td>
</tr>
<tr>
<td>114</td>
<td>0.62</td>
<td>0.078</td>
<td>9</td>
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<tr>
<td>115</td>
<td>0.25</td>
<td>0.033</td>
<td>9</td>
</tr>
<tr>
<td>116</td>
<td>0.60</td>
<td>0.135</td>
<td>9</td>
</tr>
<tr>
<td>117</td>
<td>0.47</td>
<td>0.078</td>
<td>9</td>
</tr>
<tr>
<td>118</td>
<td>0.34</td>
<td>0.049</td>
<td>9</td>
</tr>
<tr>
<td>119</td>
<td>0.57</td>
<td>0.057</td>
<td>7</td>
</tr>
<tr>
<td>120</td>
<td>0.65</td>
<td>0.049</td>
<td>8</td>
</tr>
<tr>
<td>121</td>
<td>0.36</td>
<td>0.030</td>
<td>8</td>
</tr>
<tr>
<td><strong>Mean</strong></td>
<td>0.41</td>
<td>0.061</td>
<td>11</td>
</tr>
</tbody>
</table>

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.
Figure 2.4: Concentrations at potential density horizons of 27.782, 27.758 and 27.675 (approx. 4000m, 3000m and 2000m) at Station ALOHA. [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.
2.5.4 Dissolved Organic Matter

Dissolved organic carbon (DOC) was determined by the high temperature catalytic oxidation method using an automated DOC analyzer (Qian and Mopper 1996). 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 given in Table 2.15.

Table 2.15: Precision of Dissolved organic nutrient analyses during 2000

<table>
<thead>
<tr>
<th>HOT</th>
<th>DOC CV (%)</th>
<th>DOC SD (µM)</th>
<th>N</th>
<th>DON CV (%)</th>
<th>DON SD (µM)</th>
<th>N</th>
<th>DOP CV (%)</th>
<th>DOP SD (µM)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>1.3</td>
<td>0.85</td>
<td>5</td>
<td>2.4</td>
<td>0.03</td>
<td>2</td>
<td>7.1</td>
<td>0.014</td>
<td>1</td>
</tr>
<tr>
<td>112</td>
<td>1.3</td>
<td>0.98</td>
<td>5</td>
<td>4.4</td>
<td>0.10</td>
<td>5</td>
<td>16.3</td>
<td>0.018</td>
<td>4</td>
</tr>
<tr>
<td>113</td>
<td>1.9</td>
<td>1.53</td>
<td>5</td>
<td>3.4</td>
<td>0.16</td>
<td>5</td>
<td>14.4</td>
<td>0.011</td>
<td>4</td>
</tr>
<tr>
<td>114</td>
<td>1.3</td>
<td>0.92</td>
<td>4</td>
<td>6.7</td>
<td>0.20</td>
<td>5</td>
<td>21.3</td>
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<td>4</td>
</tr>
<tr>
<td>115</td>
<td>1.1</td>
<td>0.89</td>
<td>5</td>
<td>8.1</td>
<td>0.33</td>
<td>5</td>
<td>37.1</td>
<td>0.035</td>
<td>4</td>
</tr>
<tr>
<td>116</td>
<td>1.5</td>
<td>1.03</td>
<td>5</td>
<td>9.1</td>
<td>0.27</td>
<td>5</td>
<td>30.4</td>
<td>0.034</td>
<td>4</td>
</tr>
<tr>
<td>117</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>10.1</td>
<td>0.34</td>
<td>5</td>
<td>4.2</td>
<td>0.007</td>
<td>3</td>
</tr>
<tr>
<td>118</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>6.1</td>
<td>0.58</td>
<td>5</td>
<td>16.0</td>
<td>0.012</td>
<td>4</td>
</tr>
<tr>
<td>119</td>
<td>4.6</td>
<td>2.12</td>
<td>4</td>
<td>4.8</td>
<td>0.17</td>
<td>6</td>
<td>8.6</td>
<td>0.011</td>
<td>4</td>
</tr>
<tr>
<td>120</td>
<td>8.5</td>
<td>4.95</td>
<td>5</td>
<td>3.5</td>
<td>0.11</td>
<td>6</td>
<td>12.2</td>
<td>0.008</td>
<td>6</td>
</tr>
<tr>
<td>121</td>
<td>15.4</td>
<td>7.25</td>
<td>4</td>
<td>9.7</td>
<td>0.55</td>
<td>6</td>
<td>15.3</td>
<td>0.051</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>4.1</td>
<td>2.28</td>
<td>9</td>
<td>6.2</td>
<td>0.26</td>
<td>11</td>
<td>16.6</td>
<td>0.019</td>
<td>11</td>
</tr>
</tbody>
</table>

2.5.5 Particulate Bioelements

Samples for elemental analyses of particulate matter were prefiltered through 202 µm Nitex mesh to remove large zooplankton and collected onto combusted GF/F glass fiber filters (acid washed for particulate phosphorus). Particulate carbon (PC) and nitrogen (PN) on the filters were analyzed using a Europa automated nitrogen and carbon analyzer. Particulate phosphorus (PP) was 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 2001 determined from duplicate particulate matter elemental analyses are presented in Table 2.16.
Table 2.16: Precision of Particulate matter elemental analyses during 2001

<table>
<thead>
<tr>
<th>HOT</th>
<th>PC</th>
<th>PN</th>
<th>PP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD (µg l(^{-1}))</td>
<td>N</td>
</tr>
<tr>
<td>122</td>
<td>13.2</td>
<td>1.219</td>
<td>3</td>
</tr>
<tr>
<td>123</td>
<td>6.9</td>
<td>0.647</td>
<td>2</td>
</tr>
<tr>
<td>124</td>
<td>4.7</td>
<td>0.834</td>
<td>2</td>
</tr>
<tr>
<td>125</td>
<td>11.1</td>
<td>1.980</td>
<td>2</td>
</tr>
<tr>
<td>126</td>
<td>2.5</td>
<td>0.509</td>
<td>2</td>
</tr>
<tr>
<td>127</td>
<td>1.4</td>
<td>0.255</td>
<td>2</td>
</tr>
<tr>
<td>128</td>
<td>8.0</td>
<td>1.344</td>
<td>2</td>
</tr>
<tr>
<td>129</td>
<td>9.7</td>
<td>2.319</td>
<td>2</td>
</tr>
<tr>
<td>130</td>
<td>2.3</td>
<td>0.559</td>
<td>2</td>
</tr>
<tr>
<td>131</td>
<td>7.6</td>
<td>2.553</td>
<td>2</td>
</tr>
<tr>
<td>132</td>
<td>31.8</td>
<td>14.050</td>
<td>2</td>
</tr>
<tr>
<td>133</td>
<td>3.8</td>
<td>0.336</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>8.6</td>
<td>2.217</td>
<td>12</td>
</tr>
</tbody>
</table>

2.5.6 Pigments

2.5.6.1 Standard Fluorometric Method

Chlorophyll \(a\) (chl \(a\)) and pheopigments were 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 2001 determined from triplicate analyses are presented in Table 2.17.

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 2001 are presented in Table 2.18. Figure 2.6 shows the relationship between chlorophyll \(a\) measured by fluorometry and chlorophyll \(a\) measured by HPLC during 2001.
Table 2.17: Precision of Fluorometric Chlorophyll \(a\) and Pheopigment analyses during 2001

<table>
<thead>
<tr>
<th>HOT</th>
<th>Chlorophyll (a)</th>
<th></th>
<th>Pheopigments</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean CV (%)</td>
<td>Mean SD ((\mu g\ \text{l}^{-1}))</td>
<td>N</td>
<td>Mean CV (%)</td>
</tr>
<tr>
<td>122</td>
<td>5.8</td>
<td>0.006</td>
<td>8</td>
<td>6.0</td>
</tr>
<tr>
<td>123</td>
<td>6.2</td>
<td>0.006</td>
<td>5</td>
<td>4.8</td>
</tr>
<tr>
<td>124</td>
<td>2.0</td>
<td>0.003</td>
<td>8</td>
<td>5.7</td>
</tr>
<tr>
<td>125</td>
<td>2.7</td>
<td>0.003</td>
<td>7</td>
<td>3.7</td>
</tr>
<tr>
<td>126</td>
<td>11.6</td>
<td>0.007</td>
<td>8</td>
<td>15.9</td>
</tr>
<tr>
<td>127</td>
<td>2.5</td>
<td>0.002</td>
<td>8</td>
<td>4.4</td>
</tr>
<tr>
<td>128</td>
<td>3.9</td>
<td>0.003</td>
<td>8</td>
<td>6.4</td>
</tr>
<tr>
<td>129</td>
<td>4.2</td>
<td>0.004</td>
<td>8</td>
<td>9.8</td>
</tr>
<tr>
<td>130</td>
<td>17.9</td>
<td>0.008</td>
<td>8</td>
<td>11.1</td>
</tr>
<tr>
<td>131</td>
<td>3.0</td>
<td>0.003</td>
<td>9</td>
<td>5.8</td>
</tr>
<tr>
<td>132</td>
<td>5.5</td>
<td>0.008</td>
<td>8</td>
<td>6.8</td>
</tr>
<tr>
<td>133</td>
<td>14.3</td>
<td>0.016</td>
<td>7</td>
<td>13.5</td>
</tr>
<tr>
<td>Mean</td>
<td>6.6</td>
<td>0.006</td>
<td>12</td>
<td>7.8</td>
</tr>
</tbody>
</table>

Table 2.18: 2001 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>0.250</td>
<td>0.363</td>
</tr>
<tr>
<td>Peridinin</td>
<td>0.578</td>
<td>0.391</td>
</tr>
<tr>
<td>19'-Butanoyloxyfucoxanthin</td>
<td>0.466</td>
<td>0.391</td>
</tr>
<tr>
<td>Fucoxanthin</td>
<td>0.399</td>
<td>0.423</td>
</tr>
<tr>
<td>19'-Hexanoyloxyfucoxanthin</td>
<td>0.504</td>
<td>0.463</td>
</tr>
<tr>
<td>Violaxanthin</td>
<td>0.268</td>
<td>0.548</td>
</tr>
<tr>
<td>Diadinoxanthin</td>
<td>0.320</td>
<td>0.622</td>
</tr>
<tr>
<td>Alloxanthin</td>
<td>0.344</td>
<td>0.693</td>
</tr>
<tr>
<td>Lutein</td>
<td>0.311</td>
<td>0.769</td>
</tr>
<tr>
<td>Zeaxanthin</td>
<td>0.372</td>
<td>0.785</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll b</td>
<td>1.049</td>
<td>0.939</td>
</tr>
<tr>
<td>Monovinyl Chlorophyll a</td>
<td>0.714</td>
<td>1.000</td>
</tr>
<tr>
<td>Divinyl Chlorophyll a</td>
<td>0.515</td>
<td>1.000</td>
</tr>
<tr>
<td>(\alpha)-Carotene</td>
<td>0.379</td>
<td>1.176</td>
</tr>
<tr>
<td>(\beta)-Carotene</td>
<td>0.361</td>
<td>1.182</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.
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 GFF filters and put into 100% acetone similar to the standard fluorometric method. Figure 2.7 shows the relationship between chlorophyll measured using the TD-700 & chlorophyll $a$ measured using the 10-AU as well as chlorophyll $a$, $b$ & $c$ measured by HPLC during 2001.

Figure 2.6: Chlorophyll $a$ measured by fluorometry (Chla F) versus chlorophyll $a$ measured by HPLC (Chla HPLC) for all data collected in 2001. The solid line shows the 1:1 x-y relationship while the dashed line is a model II linear regression analysis of the data set. The regression equation is at the top of the figure.
2.5.6.4 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).

![Graph showing TD-700 Chl a vs. 10-AU Chl a and TD-700 Chl b vs. HPLC Chl b](image)

![Graph showing TD-700 Chl a vs. AU-10 Chl a and TD-700 Chl c vs. HPLC Chl c](image)

Figure 2.7: Chlorophyll measured using the TD-700 versus chlorophyll measured using the AU-10 and by HPLC for all data collected in 2001. The solid line shows the 1:1 x-y relationship.
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 glass fiber filters (GFF 47 mm, Whatman) to collect the particulate material and the filters placed in boiling Tris-buffer for ATP extraction. The ATP concentrations were determined using the firefly bioluminescence technique described by Karl and Holm-Hansen (1978).

The average precisions of ATP determinations during 2001 determined from triplicate analyses are presented in **Table 2.19**.

Table 2.19: Precision of Particulate ATP analyses during 2001

<table>
<thead>
<tr>
<th>HOT</th>
<th>Mean CV (%)</th>
<th>Mean SD (ng l⁻¹)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>122</td>
<td>11.2</td>
<td>2.014</td>
<td>10</td>
</tr>
<tr>
<td>123</td>
<td>21.1</td>
<td>3.210</td>
<td>9</td>
</tr>
<tr>
<td>124</td>
<td>21.5</td>
<td>3.724</td>
<td>10</td>
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<tr>
<td>125</td>
<td>9.6</td>
<td>2.252</td>
<td>9</td>
</tr>
<tr>
<td>126</td>
<td>13.7</td>
<td>2.872</td>
<td>8</td>
</tr>
<tr>
<td>127</td>
<td>9.6</td>
<td>2.573</td>
<td>9</td>
</tr>
<tr>
<td>128</td>
<td>11.9</td>
<td>4.797</td>
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<td>129</td>
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<td>3.017</td>
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<td>132</td>
<td>16.7</td>
<td>3.397</td>
<td>9</td>
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<td>133</td>
<td>11.6</td>
<td>2.524</td>
<td>9</td>
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<tr>
<td><strong>Mean</strong></td>
<td><strong>13.5</strong></td>
<td><strong>2.876</strong></td>
<td><strong>12</strong></td>
</tr>
</tbody>
</table>

2.6 Biogeochemical Rate Measurements

2.6.1 Primary Production

Photosynthetic production of organic matter was measured by a trace-metal clean, $^{14}$C tracer method. All incubations since 1990 were conducted *in situ* at eight depths over one daylight period using a free-drifting array as described by Winn et al. (1991). 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 sediment 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 & Si. Typically three 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. This instrument measures downwelling irradiance (Ed) and upwelling radiance (Lu) as well as surface irradiance (Es) from a deck unit on 7 wavelength channels (Table 2.20). 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>
<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.

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 *Prochlorococcus* and *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 m² plankton net with a 202 µm 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⁻¹; total line out = 200 meters; 20 minute tow duration; average depth of tow ≈ 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⁻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 0.2µm 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 2001 HOT cruises. The official Chief Scientist's reports can be found on the HOT-JGOFS (hahana.soest.hawaii.edu/hot/cruises.html) and HOT-PO web pages.

3.1 HOT-122

Chief Scientist: D. HEBEL  
R/V Ka'imikai-o-Kanaloa  
15-19 January 2001

HOT-122 was conducted aboard the R/V Ka'imikai-o-Kanaloa, 15-19 Jan., 2001. Captain Ross Barnes was the master of the vessel. There was a total of 16 participants in the scientific party composed of 6 WOCE, 6 JGOFS, 2 ancillary and 2 STAG. We departed Snug on 15 January occupying stations at Kahe Pt. (sta. 1), Station ALOHA (sta. 2), HALE ALOHA (sta. 8) and Kaena Pt. (sta. 6). All scheduled work was completed and all samples collected. CTD operations were conducted at stations 1, 2, 6, 8-19. One ~1000 m CTD cast was conducted at stations 1 & 8 and ~600 m at stations 9-19. At Station ALOHA 11 ~1000 m, one ~2000 m and one ~4800 m CTD casts were completed while one ~2500m CTD cast was done at Kaena Pt. (sta.6). Other over-the-side operations at Station ALOHA included 3 light casts (PRR only), 10 net tows, 2 in situ pumping operations, floating sediment traps and primary productivity measurements. All operations followed previous cruise routines with the exception of no TSRB casts and a spacial survey (stations 9-19), of an anomalous salinity/oxygen feature at about 400m. The underway/continuous thermosalinograph, ADCP, and fluorometer were operable and functioned properly. WOCE met. obs and limited ship met. data were collected as well as discrete aerosol measurements on 15,16 & 18 Jan. Overall the weather was mostly sunny (although we did experience periods of light rain), with generally calm seas and light Trade winds.

3.2 HOT-123

Chief Scientist: D. HEBEL  
R/V Ka'imikai-o-Kanaloa  
12-16 February 2001

HOT-123 was conducted aboard the R/V Ka'imikai-o-Kanaloa, 12-16 Feb., 2001. Captain Robert Hayes was the master of the vessel. There was a total of 18 participants in the scientific party composed of 7 WOCE, 7 JGOFS, 2 ancillary and 2 STAG. We departed Snug on 12 February occupying stations at Kahe Pt. (sta. 1), Station ALOHA (sta. 2), and Kaena Pt. (sta. 6).

This cruise was very unusual in the aspect that we experienced a medical problem which required transport back to Oahu and the combination of high winds and large swells. These latter conditions prevented our usual 36 burst CTD operations and deletion of TSRB, net tows, primary productivity, in situ pumping and station 8 CTD operations. from the cruise.
schedule. In addition, the sediment trap deployment was cut short due to the rising sea state and the captain's concern that we may not be able to recover the traps at the scheduled time.

3.3 HOT-124

Chief Scientist: J. JOHNSON
R/V Ka'imikai-o-Kanaloa
19-23 March 2001

All scientific objectives were met with the schedule being shifted to fulfill the WOCE deep and shallow cast requirements. The deep WOCE cast and the immediately following shallow WOCE cast were not sampled properly which made repeating these casts at the end of the cruise necessary. Fourteen 1000-m CTD casts and two deep casts were obtained at station ALOHA. One 1000-m CTD cast was obtained at each of stations Kahe and HALE-ALOHA. One near-bottom cast (~2500 m) was obtained at station 6. The primary productivity array and the B. Popp array were deployed and recovered without problems. The array of floating sediment traps was deployed and recovered without incidents. C. Allen and T. Gregory successfully completed 6 plankton net tows. The ADCP ran without interruption throughout the cruise, as well as the thermosalinograph, the fluorometer, and the ship's anemometer. The thermosalinograph recorded noisy salinity data during the transit to station ALOHA, apparently due to bubbles introduced in the system because of the rough ride. In general, weather conditions during the cruise were excellent with variable winds and fairly calm seas.

3.4 HOT-125

Chief Scientist: F. SANTIAGO-MANDUJANO
R/V Ka'imikai-o-Kanaloa
16-20 April 2001

Operations were conducted as planned without major interruptions. Thirteen 1000-m CTD casts and two deep casts were obtained at station ALOHA. One 1000-m CTD cast was obtained at each of stations Kahe and HALE-ALOHA. One near-bottom cast (~2500 m) was obtained at station 6. The CTD wire was reterminated for regular maintenance before starting work at station HALE-ALOHA. The array of floating sediment traps and the primary productivity array were deployed and recovered without incidents. The primary productivity array drifted northwest to the edge of the ALOHA circle, and the sediment traps drifted 16 nm northwest from Station ALOHA. C. Allen and C. Benitez-Nelson completed successfully 6 plankton net tows. The in situ pump was successfully deployed as planned, as well as the PRR.

On April 17 during deployment of the TSRB, its cable got caught around the ship's propeller. A crew member had to SCUBA dive under the ship and cut the cable to untangle the buoy, the buoy and cable were recovered but were damaged and unusable for the rest of the cruise. This operation only affected one scheduled net tow, which was rescheduled for a later time.

The ADCP ran without interruption throughout the cruise, as well as the fluorometer, and the ship's anemometer. The ship's gyro interface had problems three times
during the cruise, affecting some of the ship's navigation data logging. Winds were easterlies at 20 kt, and 4-5 ft swells.

### 3.5 HOT-126

Chief Scientist: M. ERICKSON  
R/V Ka'imikai-o-Kanaloa  
14-18 May 2001

Operations were conducted as planned with minor interruptions. Thirteen 1000 m CTD casts, and two 4800 m casts were obtained at Station ALOHA. One 1000 m CTD cast was obtained at each of stations Kahe and HALE-ALOHA. One near-bottom cast (~2500 m) was obtained at Station 6. The CTD had numerous problems throughout the 36 hour period. Troubleshooting and repairing allowed for all casts to be completed except for cast 3 at Station ALOHA. The primary productivity array was deployed and retrieved as planned on May 16. The array of floating sediment traps was deployed and recovered with out incidents. The $O_2$ Flux array was successfully deployed on May 16 and recovered on May 17. C. Allen and T. Gregory successfully completed 8 plankton net tows. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermostalinograph and anemometer. Weather conditions were favorable throughout the cruise, with light winds and flat seas.

### 3.6 HOT-127

Chief Scientist: J. DORE  
R/V Ka'imikai-o-Kanaloa  
12-16 June 2001

Operations were conducted as planned without major interruptions. Thirteen 1000-m CTD casts and two deep casts were obtained at Station ALOHA. One 1000-m CTD cast was obtained at Station Kahe and two at Station HALE-ALOHA. One 1000-m cast and one near-bottom cast (~2500 m) were obtained at Station Kaena. The array of floating sediment traps, the oxygen array and the primary productivity array were all deployed and recovered without incident. None of the arrays drifted beyond the edge of the 6 nmi circle defining Station ALOHA. The sediment traps drifted southwest about 4 nmi from the center of the circle. The Argos satellite was unable to deliver positions for the oxygen array, perhaps due to the antenna in the buoy being too close to the water. The strobe on the primary productivity array appeared to have failed when recovered. C. Allen and T. Gregory completed successfully 6 plankton net tows. The *in situ* pump was successfully deployed as planned, as well as the PRR. Aerosol measurements were not completed due to cloudy conditions at the specified satellite crossover times. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermostalinograph, and the ship's anemometer. The ship's gyro had no problems during this cruise. Winds were easterlies at 10-20 kt, with 3-6 ft swells.
3.7 HOT-128

Chief Scientist: K. BJÖRKMAN
R/V Ka'imikai-o-Kanaloa
9-13 July 2001

Operations were conducted as planned with some minor interruptions. Twelve 1000-m CTD casts and one deep cast were obtained at Station ALOHA. One 1000-m CTD cast was obtained at Station Kahe and one 2000-m CTD cast at Station HALE-ALOHA. One near-bottom cast (~2500 m) was obtained at Station Kaena. The array of floating sediment traps, the oxygen array and the primary productivity array were all deployed and recovered without major incidents. All of the arrays drifted northwest fairly swiftly. The sediment traps drifted about 15 nmi from the center of the circle. The Argos satellite was unable to deliver positions for the oxygen array, even after modifications to the spar buoy to alleviate this problem since the last cruise (H127). The strobe on the primary productivity array was not activated on deployment. M. Landry, C. Sheridan, A. Senderstrom and C. Benitez-Nelson completed successfully 10 plankton net tows, plus an additional 4 surface tows. The in situ pump was successfully deployed as planned. Aerosol measurements were completed as planned at the specified satellite crossover times. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, and the ship's anemometer. The thermosalinograph's external temperature sensor did not function properly during the cruise despite attempts by S. Poulos to correct the problem. Winds were easterlies at 20 kt, with 4-5 ft swells.

3.8 HOT-129

Chief Scientist: F. SANTIAGO-MANDUJANO
R/V Ka'imikai-o-Kanaloa
6-10 August 2001

All scientific objectives were met. Fourteen 1000-m CTD casts and one deep cast were obtained at station ALOHA. One 1000-m CTD cast was obtained at station Kahe and two at HALE-ALOHA. One near-bottom cast (~2500 m) and one 300 m cast were obtained at station 6. Two shallow casts (< 600 m) were conducted at stations Kahe and ALOHA to troubleshoot problems encountered with the CTD. The array of floating sediment traps, the primary productivity array, and P. Morris' O2 array were deployed and recovered without incidents. The sediment traps array drifted 10 nm southwest from Station ALOHA. C. Allen and T. Gregory completed successfully 6 pairs of plankton net tows. The in situ pump was successfully deployed as planned, as well as the PRR. The ship's port generator had problems during transit to stations Kahe and ALOHA. This delayed the arrival to station ALOHA until 0200 (August 7). The ADCP ran without interruption throughout the cruise, as well as the thermosalinograph, fluorometer, and the ship's anemometer. Winds were easterlies at 20 kt, and 5-6 ft seas.
3.9 HOT-130

Chief Scientist: D. HEBEL
R/V Ka'imikai-o-Kanaloa
30 September - 4 October 2001

HOT-130 was conducted aboard the R/V Ka'imikai-o-Kanaloa, 30 Sept. - 4 Oct., 2001. Captain Robert Hayes was the master of the vessel. There was a total of 14 participants in the scientific party composed of 4 WOCE, 7 JGOFS, 1 ancillary and 2 STAG. We departed Snug on Sunday 30 Sept. 2001, occupying stations at Kahe Pt. (sta. 1), Station ALOHA (sta. 2), HALE ALOHA (sta. 8), and Kaena Pt. (sta. 6). During this cruise we observed a surface accumulation of Tricodesmium on Tuesday 2 Oct., primarily consisting of the sawdust colonial variety (fusiform morphology or tufts with tricomes aligned parallel), and less numerous spherical colonies (puffs, with tricomes aligned radially).

The WOCE component experienced large CTD differences between sensor pairs during some casts due to unusual ship roll. and the 36-hr period was completed on schedule and without interruptions. CTD operations were conducted at stations 1, 2, 6, & 8. One ~1000 m CTD cast was conducted at stations 1 & 8. At Station ALOHA, 13 ~1000 m and 2 ~4800 m CTD casts were completed, while one ~2500m and 3 shallower CTD casts were completed at Kaena Pt. (sta.6). The ~1000 m casts at station 6 were for instrument testing (fluorometer, cables, pylon, etc.), including a Seacat (SBE19) tested for David Murphy of Sea Bird and two Seapoint fluorometers were tested for STAG. The WOCE altimeter failed on the second deep cast, but the pinger functioned properly. The STAG's altimeter was installed before the deep cast at Kaena.

Other over-the-side operations included 3 light casts (PRR only), 10 net tows, oxygen flux, floating sediment traps and primary productivity deployments. All arrays were retrieved successfully although the stem on the base-plate of the sediment trap spar buoy parted before deployment but we were able to make adequate field repairs. Upon retrieval of the oxygen flux array the 5 and 25 m cubes were missing. The underway/continuous thermostalinograph, ADCP, and fluorometer were operable and functioned properly. Overall the weather was mostly sunny (although we did experience brief periods of rain), with very calm seas (after 1 Oct.), and generally light Trade winds.

3.10 HOT-131

Chief Scientist: K. BJÖRKMAN
R/V Ka'imikai-o-Kanaloa
21-26 October 2001

Operations were conducted as planned without any serious interruptions. Fourteen 1000-m CTD casts, two deep cast and two 200-m casts were obtained at Station ALOHA. One 1000-m CTD cast was obtained at Station Kahe and one 1000-m CTD cast at Station HALE-ALOHA. One near-bottom cast (~2500-m) and one 1000-m cast were obtained at Station Kaena. The array of floating sediment traps, the oxygen array, the primary productivity array and the alkenone array were all deployed and recovered without major incidents. All of the arrays drifted southwest ward. The sediment traps drifted about 9 nmi SW from the center of the circle.
C. Allen and C. Sheridan, successfully completed 9 plankton net tows, plus an additional 2 surface tows. The dual in situ pumps were successfully deployed as planned. PRR and TSRB measurements were successful on all deployments. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph and the ship's anemometer.

3.11 HOT-132

Chief Scientist: J. JOHNSON
R/V Ka'imiikai-o-Kanaloa
15-19 November 2001

All scientific objectives were met. Thirteen 1000-m CTD casts and two deep casts were obtained at station ALOHA. One 1000-m CTD cast was obtained at station Kahe and one at HALE-ALOHA. One near-bottom cast (~2500 m) was obtained at station 6. The array of floating sediment traps, the primary productivity array, and P. Morris' O₂ array were deployed and recovered without incidents. The sediment traps array drifted 20 nm North from Station ALOHA. C. Sheridan completed successfully 6 pairs of plankton net tows. The PRR and TSRB we successfully deployed. The ADCP ran without interruption throughout the cruise, as well as the thermosalinograph, fluorometer, and the ship's anemometer. Winds were light and variable.

3.12 HOT-133

Chief Scientist: T. GREGORY
R/V Ka'imiikai-o-Kanaloa
12-16 December 2001

One 1000-m CTD cast was obtained at both Station Kahe and Station HALE-ALOHA however we did not complete a cast at Station Kaena. PRR/TSRB deployments were successful at Station HALE-ALOHA. Heavy seas and high winds hampered operations at Station ALOHA. After waiting for the heavy weather to subside to operational levels, all CTD-related sampling goals were accomplished including the 36-hour sampling interval. Neither free-floating array deployments nor PRR/TSRB work were attempted at Station ALOHA due to extreme weather. Also, we decided to postpone recovery of the bottom moored sediment trap to a future cruise. C. Allen attempted one plankton net tow however most of the 202 µm net including the cod end was lost. The ADCP ran without interruption throughout the cruise, as well as the fluorometer, thermosalinograph and the ship's anemometer. However, thermosalinograph conductivity data was quite noisy, probably due to bubbles in the system.
4.0 RESULTS

4.1 Hydrography

4.1.1 2001 CTD Profiling Data

Profiles of temperature, salinity, oxygen and potential density (\(\sigma_\theta\)) were obtained from data collected at Stations Kahe, ALOHA, and HALE-ALOHA. The downcast CTD profiles from Station ALOHA during 2001 are presented in Figures 6.1.1a to l, together with the results of bottle determinations of oxygen, salinity and inorganic nutrients. 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 l). 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 l). In some instances mismatches are caused by freshening of the surface water due to rain during the cast.

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

Profiles of the data collected for Stations Kahe and HALE-ALOHA during 2001 are presented in Figures 6.1.4. Station HALE-ALOHA was not visited during HOT-123 because of time constraints due to a medical emergency on board.

The potential temperature, salinity and oxygen profiles obtained from the deep casts at Station ALOHA during 2001 are presented in Figures 6.1.5-7. A subsurface anomaly developed during HOT-122 centered at 400 dbar apparently caused by the passing of an eddy (Lukas and Santiago-Mandujano, 2001). This caused anomalous values in all the hydrographic variables observed at the ALOHA and at the HALE-ALOHA stations.

A cold-water anomaly developed near the bottom in April 2001 during HOT-125 (Figure 6.1.5, the coldest profile near the bottom) and started warming up in the following cruise. Similar anomalies have been observed in previous years; this is the 8\(^{th}\) major cold-water anomaly observed since the beginning of the time-series (Lukas et. al., 2001).

4.1.2 Time-series Hydrography, 1988-2001

The hydrographic data collected during the first thirteen years of HOT are presented in a series of contour plots (Figures 6.1.8-23). These figures show the data collected in 2001 within the context of the longer time-series. The CTD data used in these plots are obtained by averaging the data collected during the 36-hour period of burst sampling. Therefore, much of the
variability, which would otherwise be introduced by internal tides, has been removed. Figures 6.1.8 and 6.1.9 show the contoured time-series for potential temperature and density ($\sigma_\theta$) in the upper 1000 dbar for all HOT cruises through 2001. 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 2001. 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 has continued throughout 2001, intensifying in the first half of 1999 and during the major part of 2000 and 2001. This increase is also present in deeper layers reaching 200 dbar (Figure 6.1.10).

The salinity maximum is generally found between 50 and 150 dbar, and within the range 24-25 $\sigma_\theta$. A salinity maximum region extends to the sea surface in the later part of 1990, 1993 and during 1998, 1999, 2000 and 2001, 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 2001 reaching record values of up to 35.45 in the first half of 1999. 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).

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.

The salinity minimum is found between 400 and 600 dbar (26.35-26.85 $\sigma_\theta$). 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 is due to the eddy feature observed during HOT-122 as mentioned earlier.

*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 $\sigma_0$. This 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 eddy feature observed during HOT-122 as mentioned earlier.

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 1998, which started increasing in 1999.

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, and July-September 1999. 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 $\mu$mol kg$^{-1}$ below 27.5 $\sigma_0$ where nitrate concentrations are about 40 $\mu$mol kg$^{-1}$. This decrease appears to be real as it does have coherence over time. A precision estimate of 0.3% has been made for [nitrate + nitrite] measurements involving the high concentration samples associated with intermediate water (Dore et al., 1995). This translates to a precision of roughly 0.12 $\mu$mol kg$^{-1}$ for samples with a concentration of 40
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 2001 HOT and mooring cruises are presented in Figures 6.2.1a to l and Figures 6.2.2a to l. 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.

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 below 35.2 for the first half of 2001, increasing above this value after July.

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 l.

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. Because of the geographic separation between the buoy and station ALOHA, the buoy sea-surface temperatures are higher...
than at ALOHA by up to 1 °C, particularly during the summer and fall (Figure 6.3.1, lower panel).

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 l.

### 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 l) and velocity as a function of latitude and depth during transit to and from Station ALOHA combined (Figures 6.4.2a to l). 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 1988-2001 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 Inorganic carbon

Time-series of mixed-layer titration alkalinity and DIC from 1988-2001 are presented in Figure 6.5.2. Titration alkalinity normalized to 35 ppt salinity averages approximately 2303 µeq kg⁻¹. No obvious seasonal nor 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. (2004) 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 6.5.3 shows the profiles obtained from our low level [nitrate + nitrite] analyses at Station ALOHA during 2001. The upper 100 m is generally depleted in [nitrate + nitrite] with no values exceeding 4 nmol kg\(^{-1}\). A contour plot of LLN from 0-100 dbar during the 1989-2001 time period is shown in Figure 6.5.4.

Dissolved inorganic P (DIP) was analysed 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 6.5.5 presents the low-level SRP data from 2001. 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 1989-2001 is shown in Figure 6.5.6. Several trends are evident. First and foremost is the general reduction in DIP inventory from >90 nmol kg\(^{-1}\) in 1989-1990 to <30 nmol kg\(^{-1}\) in 2001. The 0-100 m depth integral was systematically 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 N\(_2\) 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 a less dramatic increase in 1998). The mechanism(s) controlling these inventory enhancements is not well resolved in the HOT field data.

4.5.4 Organic nutrients

Contour plots of dissolved organic carbon (DOC), nitrogen (DON) and phosphorus (DOP) from 0 to 1000 dbar over the 1988-2000 time period are presented in Figures 6.5.7-6.5.9. DOC concentrations are typically about 80-110 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 matter

Particulate carbon (PC), nitrogen (PN) and phosphorus (PP) concentrations in the surface ocean over the 13 years of the program are shown in Figures 6.5.10. PC ranges from about 1-3 µmol kg\(^{-1}\), PN from 0.1-0.6 µmol kg\(^{-1}\) and PP from 10-25 nmol kg\(^{-1}\) in the upper 100 m of the water column. An annual cycle is suggested with the greatest particulate bioelement concentrations in summer/fall and the lowest in winter. Substantial interannual variability is also noted, especially for PP.
4.5.6 Chlorophyll $a$ by fluorometry

A contour plot of chlorophyll $a$ concentrations measured using standard fluorometric techniques from 0 to 200 dbar during 1988-2001 is shown in Figure 6.5.11. A chlorophyll maximum with concentrations up to about 0.3 mg m$^{-3}$ is observed at approximately 100 m depth. The magnitude of this feature exhibits significant interannual variability, with a pronounced period of low chlorophyll concentration lasting from 1992-1998. Chlorophyll $a$ concentrations at depths shallower than 50 m display an annual cycle with winter maxima and summer minima.

4.5.7 High Performance Liquid Chromatography

Contour plots of HPLC-determined pigment concentrations from 0 to 200 dbar during 1988-2001 are shown in Figures 6.5.12-6.5.14. The pigments have been segregated into three chromophore classes: chlorophylls (chlorophyll $a$, chlorophyll $b$, and chlorophyll $c$; Figure 6.5.12), photosynthetic carotenoids (19'-butanoyloxyfucoxanthin, fucoxanthin, and 19'-hexanoyloxyfucoxanthin; Figure 6.5.13) and photo-protective carotenoids (diadinoxanthin, zeaxanthin, and $\alpha/\beta$-carotene; Figure 6.5.14).

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 1996-2001. For other key groups, such as the haptophytes and cyanobacteria, there appears to be a recent post-1996 enhancement in their biomass relative to the previous 7-year period of observation. Diatoms, on the other hand, display sharp increases during the summer months of certain years (e.g., 1998 and 2000). These interannual variations in phytoplankton populations are likely linked to climate forcing (e.g., ENSO and PDO) and are currently under investigation.
4.5.8 Adenosine 5' triphosphate

The concentration of particulate ATP resembles those of the particulate bioelements, showing maximum concentration near the surface and a decreasing profile with depth (Figure 6.5.15). 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 Productivity

The depth-integrated (0-200 m) results of the 14C incubations and pigment determinations for samples collected from CTD casts in 2001 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 13 years of the program are shown in Figure 6.6.1 in order to place the 2001 results within the context of the time-series data set. Depth-integrated rates of primary production vary seasonally, with summer maxima and winter minima. Overall, primary production varies by a factor of five, from about 200-1000 mg C m\(^{-2}\) d\(^{-1}\). However, a large majority of the primary production estimates are between 300 and 600 mg C m\(^{-2}\) d\(^{-1}\), and the overall mean value (± sd) is 498 ± 145 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 using modern methodology (Martin et al., 1987; Laws et al., 1989; Knauer et al., 1990).

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

<table>
<thead>
<tr>
<th>HOT</th>
<th>Incident Irradiance (E m(^{-2}) d(^{-1}))</th>
<th>Chl a (mg m(^{-2}))</th>
<th>Pheo (mg m(^{-2}))</th>
<th>Incubation Duration (hrs)</th>
<th>Light Assimilation Rates (mg C m(^{-2}) d(^{-1}))</th>
</tr>
</thead>
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4.6.2 Particle Flux

Particulate carbon (PC), nitrogen (PN) and phosphorus (PP) fluxes at 150 m are presented in Table 4.2 and Figure 6.6.2 for the 1988-2001 time period. All three 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 flux 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 high-flux high-variability regime (1988-1991) to a low-flux low-variability regime (1992-1996). There is a suggestion in the 1997-2001 data that the high flux and variability may be returning.

Table 4.2: Station ALOHA 2001 sediment trap flux data

<table>
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<tr>
<th>HOT</th>
<th>PC Flux (mg m(^{-2}) d(^{-1}))</th>
<th>PN Flux (mg m(^{-2}) d(^{-1}))</th>
<th>PP Flux (mg m(^{-2}) d(^{-1}))</th>
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<td>1.7</td>
<td>3.91</td>
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</table>

4.7 Microbial Community Structure

Depth profiles of counts of heterotrophic bacteria (actually non-pigmented bacteria and archaea) and photosynthetic (pigmented) bacteria for each cruise are presented in Figure 6.7.1. At the surface, heterotrophic bacterial numbers range from 3 to 8 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 counts of cyanobacteria and pigmented eukaryotes are presented in Figure 6.7.2. At the surface, *Synechococcus* numbers range from 0 to 2 x 10\(^3\) ml\(^{-1}\). They usually decrease with depth with a subsurface maxima between 50 and 100 m. Surface Eukaryotes range from 0 to 2 x 10\(^3\) ml\(^{-1}\). They generally decrease with depth, although they occasionally have subsurface maximas.
4.8 Zooplankton Community Structure

Temporal variation in mesozooplankton dry weight biomass during HOT year 13 (2001) is presented in Figure 6.8.1. HOT zooplankton dry weight was approximately 12% of the zooplankton wet weight. Only one nighttime tow was taken during HOT-123 and no tows were taken during HOT-133 due to technical difficulties.

The dry weight biomass of mesozooplankton collected during the night during 2001 (mean = 1.209 g DW m\(^{-2}\) (standard deviation, \(s = 0.214\) g DW m\(^{-2}\)) was significantly greater than the biomass of mesozooplankton collected during the day (mean = 0.808 g DW m\(^{-2}\) (\(s = 0.192\) g DW m\(^{-2}\)); Student’s T-test, n=10, p<0.001), due to the upward migration of deep-living zooplankton and micronekton after sunset. Mesozooplankton biomass averages during HOT year 13 are slightly higher than averages for all eight years of the zooplankton program (1994 – 2001; night mean = 1.019 g DW m\(^{-2}\) (\(s = 0.324\) g DW m\(^{-2}\)); day mean = 0.636 g DW m\(^{-2}\) (\(s = 0.241\) g DW m\(^{-2}\)). Nonparametric analysis reveals that nighttime zooplankton biomass during year 13 (2001) was significantly higher than nighttime biomass during 1994, 1995 and 1997 (Mann-Whitney U test, n\(\leq\)12, p\(\leq\)0.02). Nighttime biomass during 1996, 1998, 1999 and 2000 did not differ significantly from year 13 (2001).
5.0 REFERENCES


6.0 FIGURES

6.1 Hydrography

**Figure 6.1.1a-l:** [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. [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 obtained are included.

**Figure 6.1.2a-l:** [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-l:** Stack plots of chloropigment (fluorescence) versus pressure to 200 dbar [1st panel] and chloropigment versus $\sigma_0$ to 26 kg/m$^3$ [2nd panel] at Station ALOHA. Offset is .1 µg/l for both plots.

**Figure 6.1.4a-l:** [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 [nitrate + nitrite], soluble reactive phosphorus, silicate, and 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 HALE ALOHA (except for b). [Lower right panel] Plot of CTD and bottle salinity and oxygen as a function of potential temperature at Station HALE ALOHA (except for b).

**Figure 6.1.5:** [Upper panel] Potential temperature versus pressure for all deep casts in 2001. [Lower panel]: Potential temperature versus pressure deeper than 2500 dbar for all deep casts in 2001.

**Figure 6.1.6:** [Upper panel] Salinity versus potential temperature for all deep casts in 2001. [Lower panel]: Salinity versus potential temperature for all deep casts in 2001 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 2001. [Lower panel] Oxygen versus potential temperature for all deep casts in 2001 in the 1-5 °C range.

**Figure 6.1.8:** Contour plot of CTD potential temperature versus pressure for HOT cruises 1-133.

**Figure 6.1.9:** Contour plot of $\sigma_0$, calculated from CTD pressure, temperature and salinity, versus pressure for HOT cruises 1-133.

**Figure 6.1.10:** Contour plot of CTD salinity versus pressure for HOT cruises 1-133.
Figure 6.1.11: Contour plot of CTD salinity versus $\sigma_0$ to 27.5 $\sigma_0$ for HOT cruises 1-133. 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 1-133. 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 1-133. 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 1-133. 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 1-133. 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 1-121. 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 1-121. 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 1-121.

Figure 6.1.19: Contour plot of soluble reactive phosphorus versus $\sigma_0$ from 27.0 to 27.8 $\sigma_0$ for HOT cruises 1-121.

Figure 6.1.20: Contour plot of soluble reactive phosphorus versus pressure for HOT cruises 1-121. 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 1-121. 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 1-121. 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 1-121. A heavy line connects the average $\sigma_0$ at the sea surface.

Figure 6.1.24: Time series of mean bottle dissolved oxygen (upper panel), [nitrate + nitrite] (middle panel) and soluble reactive phosphorus (lower panel) between 27.0 and 27.8 $\sigma_0$ isopycnals for HOT cruises 1-121. The smooth line is the spline fit to the data. The asterisks indicate the annual mean.
6.2 Thermosalinograph

Figure 6.2.1a-l: Thermosalinograph data for each HOT cruise in 2001. Continuous near-surface temperature, salinity and \( \sigma_0 \) (continuous lines), CTD data at 4 dbar (circles), and salinity bottle data (crosses).

Figure 6.2.2a-l: Navigation data during each HOT cruise in 2001: latitude, longitude and ship speed.

6.3 Meteorology

Figure 6.3.1: [Upper panel] Atmospheric pressure while at Station ALOHA for 2001 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 2001 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 2001 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 2001 HOT cruises.

Figure 6.3.3: [Upper panel] Sea surface temperature minus dry air temperature while at Station ALOHA for 2001 HOT cruises (open circles), and NDBC buoy #51001 hourly measurements throughout the year (continuous line). [Lower panel] Relative humidity at Station ALOHA for 2001 HOT cruises.

Figures 6.3.4a to l: [Upper panel] True winds measured at Station ALOHA for 2001 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

Figure 6.4.1a to l: Velocity fields at Station ALOHA. [Upper panel] 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. [Lower panel] 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.

**Figure 6.4.2a** to l: Same as **Figures 6.4.1** except for velocity fields on the transits to and from Station ALOHA. 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 1-133 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 1-133. [Lower panel] Mixed layer dissolved inorganic carbon (normalized to 35 ppt salinity) for HOT cruises 1-133. Error bars represent standard deviation of pooled samples collected between 0 and 50 dbar.

**Figure 6.5.3**: Depth profiles from 0-150 dbar of low-level [nitrate + nitrite] at Station ALOHA for 2001 HOT cruises by the high-sensitivity chemiluminescence method.

**Figure 6.5.4** [Upper panel] Contour plot from 0-100 dbar of low-level [nitrate + nitrite] at Station ALOHA for HOT cruises 1-133. [Lower panel] 0-100 dbar integral of LLN at Station ALOHA for HOT cruises 1-133.

**Figure 6.5.5**: Depth profile from 0-250 dbar of low-level soluble reactive phosphorus at Station ALOHA for 2001 HOT cruises by the high-sensitivity magnesium induced coprecipitation (MAGIC) method.

**Figure 6.5.6** [Upper panel] Contour plot from 0-100 dbar of low-level soluble reactive phosphorus at Station ALOHA for HOT cruises 1-133. [Lower panel] 0-100 dbar integral of LLP at Station ALOHA for HOT cruises 1-133.

**Figure 6.5.7**: Contour plot from 0-1000 dbar of dissolved organic carbon at Station ALOHA for HOT cruises 1-121.

**Figure 6.5.8**: Contour plot from 0-1000 dbar of dissolved organic nitrogen at Station ALOHA for HOT cruises 1-121.

**Figure 6.5.9**: Contour plot from 0-1000 dbar of dissolved organic phosphorus at Station ALOHA for HOT cruises 1-121.

**Figure 6.5.10a**: [Upper panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-133 from 0-50 dbar. [Lower panel] Mean concentrations of particulate carbon at Station ALOHA for HOT cruises 1-133 from 50-100 dbar. Error bars represent standard deviation of pooled samples within specified depth ranges.

**Figure 6.5.10b**: Same as **Figure 6.5.10a** except for particulate nitrogen.
Figure 6.5.10c: Same as Figure 6.5.10a except for particulate phosphorus.

Figure 6.5.11: Contour plot from 0-200 dbar of fluorometric chlorophyll \(a\) concentrations at Station ALOHA for HOT cruises 1-133.

Figure 6.5.12: Contour plots from 0-200 dbar of HPLC chlorophyll (chlorophyll \(a\), chlorophyll \(b\) & chlorophyll \(c\)) concentrations at Station ALOHA for HOT cruises 1-133.

Figure 6.5.13: Contour plots from 0-200 dbar of HPLC photosynthetic carotenoid (19'-butanoyloxyfucoxanthin, fucoxanthin & 19'-hexanoyloxyfucoxanthin) concentrations at Station ALOHA for HOT cruises 1-133.

Figure 6.5.14: Contour plots from 0-200 dbar of HPLC photo-protective carotenoid (diadinoxanthin, zeaxanthin & \(\alpha\)- plus \(\beta\)-carotene) concentrations at Station ALOHA for HOT cruises 1-133.

Figure 6.5.15: Contour plot from 0-350 dbar of particulate adenosine 5'-triphosphate concentrations at Station ALOHA for HOT cruises 1-133.

6.6 Biogeochemical Rate Measurements

Figure 6.6.1: [Upper panel] Integrated (0-200 m) primary production rates from 1988-2001. Filled circles and crosses indicate \textit{in situ} and on deck incubations, respectively. Solid line represents the average production (498 mg C m\(^{-2}\) d\(^{-1}\)), dashed lines are ± one standard deviation (145 mg C m\(^{-2}\) d\(^{-1}\)). [Lower panel] 3-point running mean of integrated primary production rates. Symbols as in upper panel.

Figure 6.6.2: [Upper panel] Particulate carbon flux at 150 m measured on all HOT cruises from 1988-2001. [Center panel] Particulate nitrogen flux at 150 m measured on all HOT cruises from 1988-2001. [Lower panel] Particulate phosphorus flux at 150 m measured on all HOT cruises from 1988-2001. Error bars represent the standard deviation of determinations from triplicate traps.

6.7 Microbial Community Structure

Figure 6.7.1: Depth profiles (0-200 m) of Heterotrophic bacteria (blue) and \textit{Prochlorococcus} numbers (red) measured by flow cytometry at Station ALOHA for 2001.

Figure 6.7.2: Depth profiles (0-200 m) of Synechococcus (blue) and Eukaryote numbers (red) measured by flow cytometry at Station ALOHA for 2001.
6.8 Zooplankton Community Structure

Figure 6.8.1: Biomass of mesozooplankton collected at Station ALOHA during 2001. Nighttime and daytime 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 July 2004. 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.


7.2 Invited/Contributed Book Chapters and Refereed Publications


25. 1993 Mopper, K. and C. A. Schultz. **Fluorescence as a possible tool for studying the nature and water column distribution of DOC components**. Marine Chemistry 41, 229- 238.


30. 1994 Bjorkman, K. and D. M. Karl. **Bioavailability of inorganic and organic phosphorus compounds to natural assemblages of microorganisms in Hawaiian coastal waters**. Marine Ecology Progress Series 111, 265-273.

31. 1994 Campbell, L., H. A. Nolla and D. Vaulot. **The importance of Prochlorococcus to community structure in the central North Pacific Ocean (Station ALOHA)**. Limnology and Oceanography 39, 954-961.


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.

64. 1996 Dore, J. E. and D. M. Karl. Nitrite distributions and dynamics at Station ALOHA. Deep-Sea Research II 43, 385-402.


determination of the organic carbon flux from open-ocean surface waters. Nature 389, 951-
954.
85. 1997 Karl, D. M., R. Letelier, L. Tupas, J. Dore, J. Christian and D. Hebel. The role of
nitrogen fixation in biogeochemical cycling in the subtropical North Pacific Ocean. Nature
388, 533-538.
phosphorus pool in the oligotrophic North Pacific Ocean. Limnology and Oceanography
42, 1398-1405.
88. 1997 Karl, D. M. Oceanic carbon cycle and global environmental change: A
Proceedings of Seventh International Symposium on Microbial Ecology, Santos, Sao
Paulo, Brazil, 1995. Sociedade Brasileira de Microbiologia / International Committee of
Microbial Ecology, Brazil, pp. 163-172.
89. 1997 Lukas, R., F. Santiago-Mandujano and E. Firing. Long-term hydrographic variations
observed in the Hawaii Ocean Time-series. in proceedings of the OOPC Ocean Climate
Time-series Workshop, The Johns Hopkins University, Baltimore, Maryland, 18-20 March,
1997. GCOS Rept. No. 41, Annex XX.
90. 1997 Liu, H., L. Campbell and H. A. Nolla. Prochlorococcus growth rate and contribution
to primary production in the equatorial and subtropical North Pacific Ocean. Aquatic
Microbial Ecology 12, 39-42.
91. 1997 Sansone, F. J., B. N. Popp and T. M. Rust. Stable carbon isotopic analysis of low-
level methane in water and gas. Analytical Chemistry 69, 40-44.
exposed to the oceanic water column. Aquatic Geochemistry 3, 1-20.
93. 1997 Venrick, E. L. Comparison of the phytoplankton species composition and structure in
the Climax area (1973-1985) with that of Station ALOHA (1994). Limnology and
Oceanography 42, 1643-1648.
94. 1998 Dore, J. E., B. N. Popp, D. M. Karl and F. J. Sansone. A large source of atmospheric
organic matter release in the productivity of the oligotrophic North Pacific Ocean.
Limnology and Oceanography 43, 1270-1286.
97. 1998 Letelier, R. M. and D. M. Karl. Trichodesmium spp. physiology and nutrient fluxes in
the North Pacific subtropical gyre. Aquatic Microbial Ecology 15, 265-276.
98. 1998 Venrick, E. L. Comparison of the phytoplankton species composition and structure in
the Climax area (1973-1985) with that of Station ALOHA (1994). Limnology and
Oceanography 42, 1643-1648.


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.


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

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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. *Nitrification in lower euphotic zone at Station ALOHA: Patterns and significance*
g) Firing, E. The north Hawaiian ridge current and other flows near ALOHA
h) Hebel, D. *Temporal distribution, abundance and variability of suspended particulate matter (particulate carbon, nitrogen and phosphorus) at Station ALOHA -- Observations of a seasonal cycle*
i) Karl, D., D. Hebel, L. Tupas, J. Dore and C. Winn. *Station ALOHA particle fluxes and estimates of export production*
j) Karl, D. M., R. Letelier, L. Tupas, J. Dore, D. Hebel and C. Winn. *N2 fixation as a contributor to new production at Station ALOHA*
k) Karl, D. M., G. Tien and K. Yanagi. *Phosphorus dynamics at Station ALOHA*
l) Kennan, S. C. Possibilities for stirring along the Hawaiian ridge
m) Krothapalli, S., Y. H. Li and F. T. Mackenzie. *What controls the temporal variability of carbon flux at Station ALOHA?*

n) Letelier, R. M. *Inorganic carbon assimilation at Station ALOHA: Possible evidence of a change in carbon fluxes*
o) Letelier, R. M. *Spatial and temporal distribution of Trichodesmium sp. at Station ALOHA: How important are they?*
p) Liu, H. and L. Campbell. *Measurement of growth and mortality rates of Prochlorococcus and Synechococcus at Station ALOHA using a new selective inhibitor technique*
q) Lukas, R. and F. Bingham. Annual and interannual variations of hydrographic properties observed in the Hawaii Ocean Time-series (HOT)
r) Lukas, R., F. M. Bingham and A. Mantyla An anomalous cold event in the bottom water observed at Station ALOHA
s) Moyer, C. L., L. Campbell, D. M. Karl and J. Wilcox. *Restriction fragment length polymorphism (RFLP) and DNA sequence analysis of PCR-generated clones to assess diversity of picoeukaryotic algae in the subtropical central North Pacific Ocean (Station ALOHA)*
t) Polovina, J. J. and D. R. Kobayashi. *HOT and Hawaii's fisheries landings: Complementary or independent time-series?*
u) Sadler, D. *Time series measurement of pH at Station ALOHA*
v) Smith, C. R., D. J. DeMaster, R. H. Pope, S. P. Garner, D. J. Hoover and S. E. Doan. *Seabed radionuclides, bioturbation and benthic community structure at the Hawaii Ocean Time-series Station ALOHA*
w) Tupas, L. M., B. N. Popp and D. M. Karl. *Dissolved organic carbon in oligotrophic waters: Experiments on sample preservation, storage and analysis*

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

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

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

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

b) Bidigare, R., M. Latasa, R. Andersen and M. Keller. *A Comparison of HPLC Pigment Signatures and Electron Microscopic Observations for Oligotrophic Waters of the North Atlantic and North Pacific Oceans*

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


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

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

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

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

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


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


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


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

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

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


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

u) Santiago-Mandujano, F. and R. Lukas. *Cold Bottom Water Events Observed in the Hawaii Ocean Time-Series: Modelling and Implications for Vertical Mixing*
v) Scharek, R., M. Latasa, D. Karl and R. Bidigare. *Vertical Flux of Diatoms at the JGOFS/WOCE Station ALOHA*

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

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

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

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

aa) Winn, C. *Secular Changes in Inorganic Carbon Parameters at HOT and BATS*
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 email 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 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 data are quality controlled by around June 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 HOT Data Organization and Graphical System. It's
   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** (Rosette)
   - **Microzooplankton** (Nets)
   - **Particle Flux**
   - **Primary Production**
• Display
  • Bottle (Rosette)
  • CTD
  • HPLC Pigments
  • Particle Flux
  • Primary Production
  • Solar Irradiance
  • PRR (Ir)radiance
  • Underway Measurements
  • User Defined

• Standard Depths (vertical Water-Column)
  • Bottle (Rosette)
  • HPLC Pigments
  • Primary Production
  • User Defined

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

• Contour
  • Bottle (Rosette)
  • HPLC Pigments
  • Primary Production
  • User Defined

• Miscellaneous
  • Mixed-layer Depth
Figure 6.1.1a
Figure 6.1.1b
Figure 6.1.1c
Figure 6.1.1f
Figure 6.1.1g
Figure 6.1.1h
Figure 6.1.1i
Station ALOHA HOT 131

Figure 6.1.1j
Station ALOHA HOT 132

Figure 6.1.1k
Figure 6.1.1l
Figure 6.1.2a
Figure 6.1.2b
Figure 6.1.2c
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 6.1.2k
Figure 6.1.2I
Figure 6.1.3a
Figure 6.1.3b
Figure 6.1.3c
Figure 6.1.3d
Figure 6.1.3e
Figure 6.1.3f
Figure 6.1.3h
Figure 6.1.3i
Figure 6.1.3j
Figure 6.1.3k
Figure 6.1.31
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 6.1.4h
Figure 6.1.4i
Figure 6.1.4j
Figure 6.1.4k
Figure 6.1.4l
Figure 6.1.6
HOT 1–121 Soluble Reactive Phosphorous [umol/kg]

Figure 6.1.19
HOT 1–121 Soluble Reactive Phosphorus [umol/kg]
HOT 1−121 Mean Oxygen between Sigma–Theta 27.0 and 27.8

HOT 1−121 Mean [Nitrate+Nitrite] between Sigma–Theta 27.0 and 27.8

HOT 1−121 Mean Soluble Reactive Phosphorus between Sigma–Theta 27.0 and 27.8

Figure 6.1.24
HOT-122 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

$\sigma_{\theta}$

January 2001 (GMT)
HOT-123 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

February 2001 (GMT)

Figure 6.2.1b
HOT-126 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

May 2001 (GMT)
HOT-127 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

June 2001 (GMT)

Figure 6.2.1f
HOT-128 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

July 2001 (GMT)

Figure 6.2.1g
Figure 6.2.1h
HOT-130 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

${\sigma}_{θ}$

September–October 2001 (GMT)

Figure 6.2.1i
HOT-131 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Temperature (°C)

Salinity

σθ

October 2001 (GMT)

Figure 6.2.1j
HOT-132 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.1k
HOT-133 Thermosalinograph, o=CTD at 4 dbar, x=salinity bottle

Figure 6.2.11
HOT-122 Navigation and Ship Speed

January 2001 (GMT)
Figure 6.2.2b
HOT-125 Navigation and Ship Speed

April 2001 (GMT)
HOT-126 Navigation and Ship Speed

May 2001 (GMT)

Figure 6.2.2e
HOT-127 Navigation and Ship Speed

Figure 6.2.2f
HOT−130 Navigation and Ship Speed

September–September 2001 (GMT)

Figure 6.2.2i
HOT−132 Navigation and Ship Speed

November 2001 (GMT)

Figure 6.2.2k
HOT−133 Navigation and Ship Speed

December 2001 (GMT)

Figure 6.2.21
Figure 6.3.1
Figure 6.3.2
Figure 6.3.3
HOT 122 Shipboard True Winds, Observed

HOT 122 – True Winds, from the continuous record of the ship

HOT 122 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4a
HOT 123 Shipboard True Winds, Observed

HOT 123−True Winds, from the continuous record of the ship

HOT 123 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4b
HOT 124 Shipboard True Winds, Observed

HOT 124−True Winds, from the continuous record of the ship

HOT 124 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4c
HOT 125 Shipboard True Winds, Observed

HOT 125 - True Winds, from the continuous record of the ship

HOT 125 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4d
HOT 127 Shipboard True Winds, Observed

HOT 127−True Winds, from the continuous record of the ship

HOT 127 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4f
HOT 128 Shipboard True Winds, Observed

HOT 128−True Winds, from the continuous record of the ship

HOT 128 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4g
HOT 129 Shipboard True Winds, Observed

HOT 129−True Winds, from the continuous record of the ship

HOT 129 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4h
HOT 130 Shipboard True Winds, Observed

HOT 130–True Winds, from the continuous record of the ship

HOT 130 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4i
HOT 131 Shipboard True Winds, Observed

HOT 131−True Winds, from the continuous record of the ship

HOT 131 − True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4j
HOT 132 Shipboard True Winds, Observed

HOT 132−True Winds, from the continuous record of the ship

HOT 132 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4k
HOT 133 Shipboard True Winds, Observed

HOT 133 – True Winds, from the continuous record of the ship

HOT 133 – True Winds, buoy data (23 24N, 162 18W)

Figure 6.3.4l
Figure 6.4.1a
Harmonic Analysis of Velocity

mean + trend
semidiurnal 12.42 hours
diurnal 24 hours

Figure 6.4.1b
Figure 6.4.1c
Velocity On Station

Depth (m)

2001 Days

Harmonic Analysis of Velocity

Depth (m)

mean + trend 12.42 hours diurnal 24 hours

Figure 6.4.1d
Figure 6.4.1f
Figure 6.4.1g
2001 Days

Velocity On Station

HOT-129

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

-0.1 m/s

Figure 6.4.1h
Harmonic Analysis of Velocity

- mean + trend
- semidiurnal 12.42 hours
- diurnal 24 hours

Figure 6.4.1k
Harmonic Analysis of Velocity

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

Figure 6.4.1
Figure 6.4.2a
Figure 6.4.2b
Figure 6.4.2c
Figure 6.4.2d
Figure 6.4.2f
Figure 6.4.2j
Figure 6.4.2k
HOT 1–133 Bottle Dissolved Oxygen [μmol kg⁻¹]

Figure 6.5.1
Figure 6.5.2
HOT 1–133 Low-Level NO$_2$+NO$_3$ [nmol kg$^{-1}$]

Figure 6.5.4
Figure 6.5.5
Figure 6.5.5 continued
Figure 6.5.9

HOT 1–121 Dissolved Organic Phosphorus [μmol kg⁻¹]

Pressure [dbars]


0.05 0.1 0.15 0.2 0.25

Color scale
HOT 1–133 (0–50 dbar means)

Particulate Nitrogen [µmol kg\(^{-1}\)]

Sampling Date

HOT 1–133 (50–100 dbar means)

Particulate Nitrogen [µmol kg\(^{-1}\)]

Sampling Date

Figure 6.5.10b
HOT 1–133 19′–Butanoyloxyfucoxanthin [µg m\(^{-3}\)]

HOT 1–133 Fucoxanthin [µg m\(^{-3}\)]

HOT 1–133 19′–Hexanoyloxyfucoxanthin [µg m\(^{-3}\)]

Figure 6.5.13
Figure 6.5.14
Figure 6.6.1
Figure 6.6.2
Figure 6.7.1
Figure 6.7.1 continued
Figure 6.7.2
Year 13 (2001) HOT Zooplankton Biomass

Dry Weight Biomass (g DW m\(^{-2}\))

Day
Night

HOT Cruise Number

Figure 6.8.1