SHORT-TERM VARIATION OF WATER CHEMISTRY OFF HAWAII AND THE INFERRED VERTICAL DISPLACEMENT OF THE THERMOCLINE

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November 1988

Prepared for

University of Hawaii Fund for Project Development
Hawaii Natural Energy Institute
and
National Science Foundation
under grants
OCE86-00803 and OCE86-13647

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Abstract

Spectral analyses were performed on the chemical composition of seawater continuously pumped from 586 m depth and 1700 m offshore of the Natural Energy Laboratory of Hawaii (NELH), Keahole Point, Island of Hawaii. Seawater was collected for chemical analysis roughly weekly since August 3, 1982 and every two hours over a 52-day period in April and May, 1986. Comparing the chemistry of the pumped water with that of water collected by hydrocasts made much farther from shore has shown that the pumped water is representative of the open ocean. The salinity and the concentration of nitrate + nitrite, phosphate, and silica in the sampled water show cyclic variability over time scales of a few hours to a few years. Prominent in the time sequences of the measurements are fluctuations at periods of about 125 hours and a few years. Also, fluctuations at the semi-diurnal, diurnal, inertial (35.4 hours), and 60-hour periods are important contributors to the overall variance of the time sequences. The time sequences are highly coherent at the 95 % level and roughly in phase with one another over the entire range of periods observed, suggesting that salinity and the inorganic nutrients act as passive tracers of water motion. Cross spectra computed from the composition time sequences and concurrent sea-surface elevation and atmospheric pressure observations give clues as to the physical processes causing the observed variation in the water chemistry. Attributing the observed variation in the water composition to vertical motion of the thermocline, it seems plausible that island-trapped waves, baroclinic tides, and interannual fluctuations in the horizontal gyre circulation are principal causes. One short (21.5 hours), concurrent record of isotherm displacement in the water column directly above the NELH pipe intake (showing both upward and downward propagation of phase emanating from about 300 m depth) reinforces the speculation that a baroclinic tide was present. Local atmospheric forcing does not seem to be an important factor, but remote atmospheric forcing could be.
CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abstract</td>
<td>iii</td>
</tr>
<tr>
<td>List of Figures</td>
<td>vi</td>
</tr>
<tr>
<td>List of Tables</td>
<td>vii</td>
</tr>
<tr>
<td>Introduction</td>
<td>1</td>
</tr>
<tr>
<td>Observation and Analyses</td>
<td>1</td>
</tr>
<tr>
<td>Results and Discussion</td>
<td>4</td>
</tr>
<tr>
<td>Conclusions</td>
<td>12</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>13</td>
</tr>
<tr>
<td>References</td>
<td>14</td>
</tr>
<tr>
<td>Figures 1 - 17</td>
<td>17</td>
</tr>
<tr>
<td>Tables 1 - 3</td>
<td>29</td>
</tr>
</tbody>
</table>
FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. (A) Location of the study site, offshore of the Natural Energy Laboratory of Hawaii (NELH) at Keahole Point</td>
<td>19</td>
</tr>
<tr>
<td>(B) Configuration of the deep-water intake pipe at NELH</td>
<td>19</td>
</tr>
<tr>
<td>2. Concentration of dissolved silica in the pumped deep water at NELH from April through May, 1986</td>
<td>20</td>
</tr>
<tr>
<td>3. Vertical profiles of mean salinity, and mean silica, nitrate + nitrate, and phosphate concentrations in the vicinity of Keahole Point</td>
<td>20</td>
</tr>
<tr>
<td>4. Autospectra of salinity and silica and their coherence and phase spectra from the 52-day records</td>
<td>21</td>
</tr>
<tr>
<td>5. Autospectra of phosphate and N + N and their coherence and phase spectra from the 52-day records</td>
<td>21</td>
</tr>
<tr>
<td>6. Autospectra of salinity and phosphate and their coherence and phase spectra from the 52-day records</td>
<td>22</td>
</tr>
<tr>
<td>7. Autospectra of sea level at Kailua-Kona harbor and silica and their coherence and phase spectra from the 52-day records</td>
<td>22</td>
</tr>
<tr>
<td>8. Autospectra of sea level at Kailua-Kona harbor and sea level at Hilo harbor and their coherence and phase spectra from the 52-day records</td>
<td>23</td>
</tr>
<tr>
<td>9. Autospectra of atmospheric pressure at Kona airport and at Hilo airport and their coherence and phase spectra from the 52-day records</td>
<td>23</td>
</tr>
<tr>
<td>10. Autospectra of silica and atmospheric pressure at Kona airport and their coherence and phase spectra from the 52-day records</td>
<td>24</td>
</tr>
<tr>
<td>11. Sea level at Kailua-Kona Harbor (top panel) and isotherm displacements above the intake pipe during a 21.5-hour period in April 27-28, 1986</td>
<td>24</td>
</tr>
<tr>
<td>12. Kona sea level vs. isotherm depth cross-correlation functions for each of the isotherms</td>
<td>25</td>
</tr>
</tbody>
</table>
13. Time lags relative to Kona sea level corresponding to the maximum and minimum of the cross-correlation functions ............................................................ 25

14. Autospectra of salinity and silica and their coherence and phase spectra from the long-term monitoring records ........................................................................ 26

15. Autospectra of phosphate and N + N and their coherence and phase spectra from the long-term monitoring records ....................................................................... 26

16. Autospectra of salinity and phosphate and their coherence and phase spectra from the long-term monitoring records ........................................................................ 27

17. Autospectra of sea level at Honolulu and silica and their coherence and phase spectra from the long-term monitoring records .......................................................... 27

TABLES

Table Page

1. Vertical concentration gradients from Fig.#3, observed temporal variation in NELH seawater during the 52-day experiment, and computed signal strength ........................................ 31

2. Amplitudes of the Fourier components of the vertical displacement of the water column at the dominant tidal periods ........................................................................ 31

3. Significant coherences (95% confidence level) found between the various time sequences of the 52-day experiment ........................................................................ 32
Introduction

Water composition in the ocean below the mixed layer and seasonal thermocline is generally considered to be constant through time. Evidence for this constant composition appears to be largely circumstantial. Relatively widespread spatial sampling of deep-ocean water composition has demonstrated that spatial gradients tend to be slight (Reid, 1965), suggesting, but hardly proving, a general lack of temporal variability; however, vertical motion can be expected to introduce temporal variation in water composition at depths where significant vertical gradients occur. This study investigates the temporal variation of water composition at one such location.

The study site is the ocean immediately adjacent to Keahole Point, on the west coast of the Island of Hawaii, where the Natural Energy Laboratory of Hawaii (NELH) (Fig. 1A) operates an ocean thermal energy conversion (OTEC) test facility. Seawater has been continuously pumped at NELH from a depth of 586 m since August, 1982. This facility has been used as a "pipe of opportunity" for sampling seawater from the base of the thermocline. A comparison of the chemical composition of the pumped seawater with that of offshore seawater collected by hydrocasts has demonstrated that there is no discernable "island mass" effect on the mean composition (Smith and Walsh, 1988). In this investigation, both (roughly) weekly "monitoring" data routinely collected by NELH and a specific time sequence sampling experiment are used to ascertain the dominant periods of the temporal variation of the water chemistry and their amplitudes. In addition, some speculation is made about what phenomena may be producing the observed fluctuations.

Observations and Analyses

Deep water at Keahole Point is drawn through a pipe intake approximately 1700 m from the shore at a depth of 586 m (Fig. 1B). The inlet is approximately 30 m above the sea floor; the
mean slope of the sea floor at this location is approximately 20 degrees. The average residence
time for water in the pipe is approximately 1 hour. Further details about the facility are given by

Water composition has been continuously measured at roughly weekly intervals by NELH
since August, 1982. The time sequence analyses described herein use only salinity and the con-
centration of the dissolved nutrients NO$_3^-$ + NO$_2^-$ (herein referred to as N+N), PO$_4^{3-}$ (P), and
silica (Si). Regularly spaced time sequences of the concentrations were made via cubic spline in-
terpolation onto a 7-day grid starting August 3, 1982 and ending March 24, 1987. Temperature
measurements are not included because of the variation in the temperature of the pumped water
due to heat transferred through the pipe by the surface seawater, and the variability in the pumping
rate.

In addition to this set of monitoring data, three sets of more rapidly sampled time sequences
of salinity and nutrient data have been collected. A preliminary set of hourly samples taken over
24 consecutive hours was reported by Smith and Walsh (1988) and Sansone and Smith (1985). A
second set of data was collected at hourly intervals over 8 days in September 1985. These first
two data sets reveal no results different from a third experimental series and, therefore, will not be
discussed in this paper. The third set of experimental data was collected at 2-hour intervals over 52
days in April–May, 1986 and is the major topic of this paper. This data set had two interruptions
in the salinity record: 20 hours on the 12th day, and 12 hours on the 18th day. The mean salinity
was substituted for the missing values in the time sequence.

Nutrient samples collected during the long-term monitoring program were filtered and frozen
immediately upon collection, then held for later analysis on a Technicon Autoanalyzer II (as de-
scribed by Smith et al. (1986)). Samples were collected during the latter two time sequence
experiments with an ISCO (Lincoln, Neb.) model 1680 sampler and were frozen (unfiltered) within
24 hours for later analysis. Pilot experiments demonstrated insignificant changes in nutrient content resulting from such treatment, although samples which remained at room temperature longer than 24 hours showed measurable decreases in both N+N and P (but not Si). The approximate precision of individual analyses was as follows: N+N = 1 μM; P = 0.1 μM; Si = 1 μM.

Salinity analyses were performed on unfrozen aliquots of the samples using a Grundy Environmental Systems model 6230N laboratory inductive salinometer that was standardized daily against standard seawater (Institute of Oceanographic Sciences, Wormley, U.K.), and hourly against a secondary standard consisting of a 20 L batch of deep seawater preserved with HgCl₂. The precision of individual analyses was approximately ±0.01 x 10⁻³.

In addition to the water chemistry, concurrent sea-level and atmospheric-pressure records were collected to aid in the interpretation of the water composition time sequences. Analog sea-level records from a gage at neighboring Kailua-Kona harbor (Fig. 1A) were obtained from the Honolulu office of the Pacific Tsunami Warning Center and subsequently digitized at the 2-hour sampling interval of the chemical data. Digitized records of sea level at Hilo harbor (Fig. 1A) and surface atmospheric pressure at the major airports nearest the sea-level gages (Kona and Hilo airports) were also obtained. Sea-level data were then corrected for the "inverted barometer" effect using the approximate relationship 100.0 Pa (1.0 mbar) of atmospheric pressure = 0.0101 m sea-level elevation. Use was also made of monthly mean sea-level records at Honolulu, concurrent with the long-term monitoring data, and not corrected for atmospheric pressure. The monthly means were treated as observations made on the 15th day of the corresponding month, and the resultant time-sequence was interpolated via cubic splines onto the same regularly spaced 7-day grid of the monitoring data.

Autospectra were computed by the Fourier decomposition of the time sequences and averaging over non-overlapping blocks of frequencies. Five frequencies were averaged in each block.
in the spectra derived from the 2-hourly data, and three frequencies were averaged in spectra derived from the weekly data. The frequencies plotted in the figures of this report correspond to the centers of these blocks; the unit of the autospectral estimates is that of energy density or \( \text{amplitude}^2 \text{ frequency}^{-1} \). The cross spectra are presented in the form of coherence amplitude and phase spectra. The autospectra presented in the figures were computed from normalized time sequences (i.e. means were subtracted and residuals divided by their standard deviation for ease of comparison). The autospectra were also computed directly from the observations in order to compute the magnitudes of the spectral components.

Finally, expendable bathythermograph (XBT) probes were dropped directly over the pipe intake at roughly hourly intervals for 21.5 consecutive hours overlapping the 52-day records. Time sequences of the displacement of several isotherms from their mean depths were derived and constitute the only whole-water column measurements available during this time period. Cross-correlation functions between each isotherm displacement time sequence and sea level at Kailua-Kona harbor were calculated.

**Results and Discussion**

Figure 2 presents the Si data from the 52-day experiment. Three versions of the data are presented: (A) illustrates the raw data, (B) illustrates the data processed through a 3-point triangular running mean filter designed to smooth the data for inspection of relatively high frequency variability, and (C) shows the result of applying an 11-point filter of the same type to the raw data in order to reveal longer-term trends. Similarly filtered data sets were also obtained from the salinity, and the N+N and P concentration time sequences (data not shown). These data indicate that seawater composition at a depth of 586 m adjacent to Keahole Point, Hawaii is not constant, even though the mean composition closely approximates open-ocean mean composition for this
portion of the Pacific Ocean (Smith and Walsh, 1988). In particular, a periodicity of about 120 - 150 hours is prominent, in addition to the anticipated diurnal and semi-diurnal tidal periods.

It is hypothesized that most of the observed variation in water composition is a consequence of vertical water motion associated with internal waves or other processes, and that the amplitude of an observed signal is the product of the mean vertical gradient and the vertical displacement of the water column feeding the pipe. Figure 3 shows the vertical profiles of mean salinity, and mean Si, N+N, and P concentrations in the vicinity of the southern portion of the Hawaiian Islands (data from Wyrtki and Kilonsky (1982)). Note that, at the 586-m depth of the pipe intake, Si shows a stronger vertical gradient than the other nutrients, and salinity shows a relatively weak vertical gradient. Table 1 quantifies the relationship between the observed signal amplitudes and the inferred vertical displacements of the water column, using standard deviations (rather than spectral amplitudes) as a measure of the signal strength. The largest signal-to-noise ratio was that of Si, which, in addition, had the smallest detectable vertical displacement of the water column. Thus, Si is emphasized in this analysis.

It is important to note that the pipe intake is only about 30 m above the (steep) ocean bottom and could be residing in some sort of boundary layer. If so, the mean concentration gradients observed in the deep ocean (Fig. 3) may not represent the gradients at the location of the pipe intake. Mixing due to bottom stress might weaken the gradients and cause an underestimation of the vertical displacements inferred; however, the (nearly) 5-year means of the observed salinity, and Si, N+N, and P concentrations (34.30 × 10⁻³, 75 μM, 39 μM, and 3.0 μM, respectively) are very close to the 500 m values of the mean deep-ocean profiles. Thus, inferring the mean concentration gradients from neighboring deep-ocean profiles seems reasonable.

In order to deduce what processes might be responsible for the inferred vertical displacements, five types of cross-spectral comparisons were performed:
Nutrient concentration vs. nutrient concentration Are the measured constituents mutually coherent? This is necessary if they are acting as passive tracers of water motion.

Nutrient concentration vs. sea level at Kailua-Kona Are the fluctuations at thermocline depth reflected in the overlying sea level? This would be the case if barotropic phenomena were dominant. Also, a surface manifestation of baroclinic motion is, in principle, possible.

Sea level at Kailua-Kona vs. sea level at Hilo Are the sea-surface fluctuations coherent around the island? This would be the case if island-trapped waves were present and sufficiently energetic (Luther (1985)).

Nutrient concentration vs. atmospheric pressure at Kailua-Kona Is the atmospheric pressure variation reflected in the internal fluctuations? If meteorological factors were forcing the thermocline motion, this might be the case. Here, local wind stress, as well as direct pressure forcing, is assumed to be indicated by the local atmospheric pressure. (This assumption might be too simplistic.)

Atmospheric pressure at Kailua-Kona vs. atmospheric pressure at Hilo If there is atmospheric forcing of the thermocline off Kona, is it locally forced in the lee of Hawaii (relative to the tradewinds) (no coherence between them), or is it of larger scale (significant coherence between them)?

It was found that the nutrient concentrations and salinity are fairly coherent and in phase with one another as would be expected if they were merely passive followers of water motion. Figure 4 shows the energy spectra of salinity and Si concentration and their coherence and phase spectra. Both energy spectra exhibit peaks at the semi-diurnal period and less prominent ones at the diurnal period. (The tide in Hawaii is of the “mixed” type with prominent diurnal and
Also, there are peaks in the Si spectrum around 31 hours, just short of the inertial period of 35.4 hours, and around 125 hours, approximately the dominant period seen directly in the time sequence (Fig. 2C). Their cross spectrum exhibits significant coherence amplitudes (at the 95% level) and near zero phase differences at almost all periods. Between 36 and 125 hours the coherence is not significant, but in the salinity – N+N (not shown) and salinity – phosphate coherence spectra, several estimates in this period range were significant.

N+N and phosphate concentrations also fluctuate fairly coherently and roughly in phase (Fig. 5), as would be the case with biological activity acting alone. The salinity – phosphate coherence (Fig. 6) was the weakest of all, with only a third of the estimates significant; among them were those at the tidal and inertial periods. Overall, the time sequences of the four measured quantities give largely redundant information, suggesting that they can be regarded as passive tracers of water motion over the time scales investigated (4.0 hours to a few tens of days). Cross spectra with the Si concentration demonstrate the highest coherence, as compared to those between other constituents. This is not surprising, because Si has the largest signal to noise ratio (Table 1), as previously mentioned.

Lacking simultaneous measurements of the currents in the area, it is difficult to identify the physical processes whose signatures might be manifest in the fluctuations of chemical concentration; however, sea-level and sea-surface atmospheric-pressure records near Keahole Pt. somewhat mitigate this lack of information. (These records will be referred to as Kona records.) Also, the short temperature record gives concurrent information about the displacement of the whole water column overlying the pipe intake.

The coherence amplitude and phase of the fluctuations within the water column can be seen in the various chemical concentration – sea level cross spectra. The Si concentration – Kona sea level cross spectrum (Fig. 7), for example, shows significant coherence at 50 to 60 hours and
at the inertial and semi-diurnal periods and at a few shorter periods. Interestingly, no significant coherence occurs at the diurnal period, and the relative phases at the dominant tidal periods are far from zero (i.e. the fluctuations are not in phase). This was true of the other nutrient/salinity - Kona sea level cross spectra as well.

The coherence at 50 to 60 hours may be indicative of a particular phenomenon. In an analysis of sea level around the island of Hawaii, Luther (1985) found evidence for the existence of sub-inertial island-trapped waves, baroclinic Kelvin-like waves with wave periods longer than the local inertial period. The theoretically predicted gravest mode around Hawaii has a wave period of 59 hours. The sea-level records he analyzed supported the idea that such a wave exists. (A complex demodulation of sea-level records at Hilo harbor, whose strongest non-tidal peak was at 59 hours, showed that the amplitude of the 59-hour oscillation was greatest during winter.)

Following Luther, the cross spectrum between the sea levels at Kona harbor and at Hilo harbor was computed (Fig. 8). In addition to the expected high coherence at the diurnal and semi-diurnal periods, significant coherence in the vicinity of 59 hours, the inertial period, and at 18 to 19 hours was found. The estimate of relative phase of plus 56 degrees (Kona leading Hilo) at about 59 hours is compatible with the interpretation that this is a manifestation of the gravest mode island-trapped wave. Luther also investigated the super-inertial range and predicted a 17-hour island-trapped wave for the island of Hawaii too. Although the sea-level cross spectrum (Fig. 8) suggests this too, the Kona sea-level - subsurface chemical concentration cross spectra (Fig. 7 and other spectra not shown) shows no coherence in the vicinity of 17 hours. (The subsurface signature of such a wave is not apparent.) Also seen in the coherence spectra of Figure 8 are significant estimates at periods shorter than 12 hours. These may be manifestations of shallow water tides in the area.

The clear 125-hour periodicity seen in the Si (Fig. 2C) and other chemical time sequences
appears as a prominent peak in the autospectrum of Si (the third spectral estimate), but no corresponding peak was found in the Kona sea-level autospectrum (Fig. 7), and there was no significant coherence at this period (i.e. the periodicity seems to be only subsurface). Initially, it was suspected that this most prominent variability in the nutrient concentration was due to the local weather, perhaps in the form of Ekman pumping. This idea was encouraged by the fact that atmospheric pressure at Kona and Hilo airports are significantly correlated at the 125-hour period (Fig. 9), roughly the characteristic time scale of local weather fluctuations. However, the Si - Kona atmospheric pressure cross spectrum (Fig. 10) shows no significant coherence at 125 hours (but significant coherence at a neighboring estimate). No significant 125-hour coherence was found between Kona atmospheric pressure and salinity or the other nutrients.

Possibly, the complex and high mountain relief of the island facilitates fluctuations in small-scale wind stress curl patterns not mirror-imaged in the time variability of larger-scale atmospheric pressure fluctuations. The lack of coherence between the inferred vertical thermocline displacement and Kona atmospheric pressure, would, therefore, not rule-out Ekman pumping, for example. In any case, it is difficult to see how any kind of local atmospheric forcing could so prominently directly disturb the thermocline without noticeably affecting the overlying surface. Apparently, this 5-day atmospheric variability is not directly coupled to the same-period variability in the subsurface disturbances. Remote atmospheric forcing communicated horizontally through the thermocline is a possibility, though.

Returning again to the coherence spectrum of Si and Kona sea level (Fig. 7), the lack of significant coherence at the diurnal (but not semi-diurnal) tidal period can be explored further. The coherence spectra between Kona sea level and salinity, and between Kona sea level and the other nutrients showed the same pattern. The average relative phase of the semidiurnal component weighted by the signal to noise ratios (Table 1) is 56 degrees (nutrient concentration leading Kona
sea level); that of the diurnal component is -107 degrees. In addition, the amplitude of the diurnal component is attenuated with depth relative to the semidiurnal component. The Si spectrum and mean concentration profile imply a vertical displacement of the thermocline of 3.6 m and 7.4 m at the diurnal and semi-diurnal periods, respectively, or a ratio of 0.5 diurnal to semi-diurnal (Table 2). The diurnal and semi-diurnal sea-level components, however, are 13.6 cm and 12.1 cm, and their ratio is 1.1. (Lisitzin (1974) reports a (K1+O1)/(M2+S2) amplitude ratio of 1.09 at Honolulu.)

Clearly, the vertical displacements at depth are much larger than those attributable to the barotropic tides, and the relative phases argue further that the subsurface fluctuations are due to another process or processes — possibly baroclinic tides. Some bottom slopes around Hawaii are, theoretically, steep enough for the generation of baroclinic tides. If the source of the energy is the barotropic tide converted into baroclinic motion, the conversion process is a non-linear one, otherwise the diurnal to semi-diurnal amplitude ratio would be preserved.

Fully exploring the possible manifestation of a baroclinic tide in the area is hampered by the lack of concurrent measurements of the currents. However, the record of isotherm displacements (Fig. 11) offers some limited additional help. After computing and plotting the cross correlation functions (Fig. 12) between Kona sea level (also shown in Fig. 11) and each isotherm displacement time sequence, a depth-dependent phase shift is apparent. Note also the change in the pattern exhibited by the colder isotherms (6.5° C - 12.5° C) over that exhibited by the warmer isotherms (15.0° C - 25.0° C). A plot of the lags at maximum and minimum cross correlation vs. depth (Fig. 13) suggests an upward and downward propagating signal emanating from about 300 meters depth. This might be further evidence of the baroclinic tide.

One additional data set available for consideration comes from subsurface current meters deployed from a single mooring off Kahe Point, on the leeward coast of Oahu over a 2-year period (uninterrupted record lengths from 2 to 6 months) (Vithanage, 1987). Leeward Oahu also has steep
bottom topography and may be comparable to leeward Hawaii. The records show a somewhat complex depth dependence in magnitude and orientation of the tidal current ellipses. Each of seven diurnal and semi-diurnal components resolved had a different depth profile. Only the profile of the S2 component was at all characteristic of the barotropic tide. The dominant M2 and K1 components manifested an apparent baroclinic structure superposed on the barotropic tide.

A summary of which cross spectra revealed significant coherence at what periods in the 52-days data set is presented in Table 3. Although this cursory analysis does not prove any cause and effect relationships, some clues about the dynamical processes operating in the area can be gleaned from the information presented.

Some of the same analyses can be performed on the longer-term monitoring data (almost 5-years duration). Over the time scales of 2 weeks through a few years, the measured sea-water constituents also appear to be relatively coherent and in phase with one another (Figs. 14 - 16): they continue to act as passive tracers, and their temporal variability is also not negligible. A comparison with sea level at Kona is not possible since the Kona sea-level gage was non-existent for most of the time interval over which chemical data exists. However, regarding these longer-period fluctuations as a consequence of large length scale processes, a comparison with sea level at Honolulu is reasonable. Figure 17 presents the cross spectrum of Si and sea level at Honolulu not corrected for atmospheric pressure (the Honolulu records are monthly means, so signals with periods shorter than 2 months are not manifest in the time sequence).

In all of the salinity/nutrient vs. sea level at Honolulu coherence spectra, significant coherence was found at periods greater than one year, with corresponding phase of about 180 degrees. High sea level occurred concurrently with a depressed thermocline on an interannual time scale, which is consistent with the idea that horizontal advection of surface water into the area causes a net increase in the local volume of water (Sansone, et al., 1988). Significant coherence also occurred...
sporadically at periods of two to six months and may well be a matter of chance rather than a “true” correlation.

The record length was not long enough to resolve the annual period with great statistical significance. Sacrificing certainty in the spectral energy estimates for better resolution in frequency, the energy spectra were computed by averaging over two instead of three frequencies, as was previously done. The resultant salinity/nutrient vs. Honolulu sea-level coherence spectra (not shown) exhibited no significant coherence at the annual period, even at the 80% level. The only clear salinity/nutrient vs. sea level correlation happens at time scales of a few years, due, perhaps, to interannual fluctuations in the circulation of the subtropical gyre.

**Conclusions**

The data presented indicate that the chemical composition of thermocline-depth seawater has cyclic variability on time scales ranging from a few hours to a few years, in contrast to the commonly held belief that open ocean seawater composition is largely constant at these depths over sub-geologic time scales.

Spectral analyses of the compositional variation and concurrent sea-level and atmospheric-pressure fluctuations suggest some physical processes that might be responsible for the observed variability. These include island-trapped waves, baroclinic tides, and interannual fluctuations in the horizontal gyre circulation. The temperature structure exhibits upward and downward propagation of some signal, thus reinforcing the speculation about a baroclinic tide in the area. Local atmospheric forcing does not seem to be an important factor, but remote atmospheric forcing could be.

At present the NELH facility at Keahole Point provides a unique opportunity for continuous analysis of water composition below the mixed layer. Similar, but perhaps smaller-scale, fixed-
location pumping systems could be useful tools for studying midwater oceanic processes at other sites exhibiting vertical chemical gradients. Certainly the planned deployment of OTEC facilities on other islands (e.g., Yuen (1981)) presents convenient opportunities to extend this research to other locations at minimal cost.

Acknowledgments

Many thanks are extended to Tom Daniel of NELH for generously providing the weekly seawater composition data and for his extensive assistance and encouragement. We also thank Jim Bryan, who was responsible for the graphics production, Barbara Lee of NELH for her assistance with the sample collection and salinity analyses, Ted Walsh of the Hawaii Institute of Marine Biology Analytical Services for the high precision nutrient analyses, Professor Klaus Wyrtki and Shikiko Nakahara for access to the Hilo and Honolulu sea-level records, and Howard Tatum of the U.S. National Weather Service at Hilo Airport for the atmospheric pressure data at Kona and Hilo airports.

This research was supported by the University of Hawaii Fund for Project Development, the Hawaii Natural Energy Institute, and the U.S. National Science Foundation (grants OCE86-00803 (F.J.S.), and OCE86-13647 (S.V.S.)). This is Hawaii Institute of Geophysics Technical Rept. 88-2.
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Fig. 1A. Location of the study site, offshore of the Natural Energy Laboratory of Hawaii (NELH) at Keahole Point.

Fig. 1B. Configuration of the deep-water intake pipe at NELH.
Fig. 2. Concentration of dissolved silica in the pumped deep water at NELH from April through May, 1986. The time sequence of the raw data: (A) was passed through a 3-point triangular running mean filter to produce the partly smoothed time sequence (B). The smoother sequence (C) was produced by filtering (A) with an 11-point triangular running mean filter.

Fig. 3. Vertical profiles of mean salinity, and mean silica, nitrate + nitrite, and phosphate concentrations in the vicinity of Keahole Point. Data from Wyrtki and Kilonsky (1982).
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Fig. 5. Autospectra of phosphate and N+P and their coherence and phase spectra from the 52-day records.
Fig. 6. Autospectra of salinity and phosphate and their coherence and phase spectra from the 52-day records.

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Fig. 8. Autospectra of sea level at Kailua-Kona harbor and sea level at Hilo harbor and their coherence and phase spectra from the 52-day records.

Fig. 9. Autospectra of atmospheric pressure at Kona airport and at Hilo airport and their coherence and phase spectra from the 52-day records.
Fig. 10. Autospectra of silica and atmospheric pressure at Kona airport and their coherence and phase spectra from the 52-day records.

Fig. 11. Sea level at Kailua-Kona harbor (top panel) and isotherm displacements above the intake pipe during a 21.5-hour period in April 27-28, 1986.
Fig. 12. Kona sea level vs. isotherm depth cross-correlation functions for each of the isotherms.

Fig. 13. Time lags relative to Kona sea level corresponding to the maximum (solid curves) and minimum (dashed curve) of the cross-correlation functions.
Fig. 14. Autospectra of salinity and silica and their coherence and phase spectra from the long-term monitoring records.

Fig. 15. Autospectra of phosphate and N+N and their coherence and phase spectra from the long-term monitoring records.
Fig. 16. Autospectra of salinity and phosphate and their coherence and phase spectra from the long-term monitoring records.

Fig. 17. Autospectra of sea level at Honolulu and silica and their coherence and phase spectra from the long-term monitoring records. (The sea-level record was derived from monthly means, so it contains no components of frequency higher than one cycle per 60 days. Therefore the higher frequency phase and coherence estimates are meaningless and have been deleted.)
Table 1. Vertical concentration gradients from Fig. 3, observed temporal variation in NELH seawater during the 52-day experiment, and computed signal strength. Concentration (conc) is expressed as g/kg for salinity, and as μM for Si, N+N, and P.

<table>
<thead>
<tr>
<th></th>
<th>Si</th>
<th>Salinity</th>
<th>N+N</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A) Vertical gradient (conc/m)</td>
<td>0.084</td>
<td>0.00078</td>
<td>0.023</td>
<td>0.0017</td>
</tr>
<tr>
<td>(B) Observed variation (1σ) (conc)</td>
<td>2.98</td>
<td>0.0197</td>
<td>0.968</td>
<td>0.084</td>
</tr>
<tr>
<td>(C) Analytical variation (1σ) (conc)</td>
<td>1</td>
<td>0.01</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>(D) Signal/noise (B/C)</td>
<td>3.0</td>
<td>2.0</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>(E) Minimum observable vertical displacement (m) (C/A)</td>
<td>12</td>
<td>13</td>
<td>43</td>
<td>59</td>
</tr>
</tbody>
</table>

Table 2. Amplitudes of the Fourier components of the vertical displacement of the water column at the dominant tidal periods: the displacement at 586 m inferred from Si concentration (Si conc), and the displacement at the surface observed from sea level measurements at Kailua-Kona harbor (Sea level).

<table>
<thead>
<tr>
<th></th>
<th>Si conc</th>
<th>Sea level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diurnal period</td>
<td>3.6 m</td>
<td>13.6 cm</td>
</tr>
<tr>
<td>Semi-diurnal period</td>
<td>7.4 m</td>
<td>12.1 cm</td>
</tr>
<tr>
<td><strong>Diurnal period displacement</strong></td>
<td>0.49</td>
<td>1.12</td>
</tr>
<tr>
<td><strong>Semi-diurnal period displacement</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 3. Significant coherences (95% confidence level) found between the various time sequences of the 52-day experiment. Nut = nutrient concentrations and salinity. SL = sea level. AP = atmospheric pressure. ITW = island-trapped wave.

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Weather</td>
<td>70-100</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ITW</td>
<td>59</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inertial oscillation</td>
<td>35</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>Diurnal tide</td>
<td>24</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>ITW</td>
<td>17</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Semi-diurnal tide</td>
<td>12</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Shallow water tides</td>
<td>6, 8</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
</tbody>
</table>

1No significant coherence at the 125-hour period was found.