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Seiching in Monterey Bay.

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by

David Brooks Robinson

United States
Naval Postgraduate School

THESIS

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by

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requirements for the degree of

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ABSTRACT

The effect of the Monterey Submarine Canyon on seiching in Monterey Bay is not well known. Spectral analyses of simultaneous tidal records from the north-south extremities of the bay were performed for 23 January and 20 April 1969 to investigate this effect. Both day's records had long-wave activity of which seiching was at least a contributing mechanism. Analyses of the computed spectra for the periods during the long-wave activity, and ten-hour periods both before and after, indicate that the seiching motion in Monterey Bay has similar amplitudes at the north-south extremities.

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ACKNOWLEDGEMENT

The author wishes to express his sincere appreciation to Professor Theodore Green, III under whose direction this paper was written. His encouragement, criticism, and experience were invaluable in the completion of this research.

In addition, the author is indebted to Mr. Sheldon Lazanoff, the Naval Oceanographic Office Liaison with Fleet Numerical Weather Central, for his technical advice and assistance in installing and calibrating the tide gage in Santa Cruz, and to the Naval Oceanographic Office for the use of the portable tide gage used in this study.

I. INTRODUCTION

Monterey Bay, a large, semi-elliptical bay, is located approximately sixty nautical miles south of San Francisco. It is bounded on the north by Point Santa Cruz and on the south by Point Pinos. The bay is bisected by the Monterey Submarine Canyon. The head of this deep canyon is located just off Moss Landing (Figure 1).

Several studies have been conducted to investigate the long-period waves in the bay and its adjoining harbors. (For purposes of this research, a long-period wave is defined as any wave with a period greater than 1 min.) Hudson [1949] investigated the surge in Monterey harbor for the U.S. Army Corps of Engineers. The study provided data for a proposed model of the harbor. He used six months of continuous data (October 1946 to April 1947) obtained by three automatic Stevens water-level recorders which were electrically synchronized. The recorders were located within the present boundaries of the harbor. Hudson's results for long-period waves are shown in Table. I. The cause of these long-period waves in the harbor was not known and Hudson did not attempt to define the surge mechanism.

Wilson, et al [1965] , also working under the auspices of the Corps of Engineers, made a field study for a proposed surge-action model of Monterey harbor. Wilson analyzed the long-period waves in the entire bay, using data from several sources. Wave recorders installed by Marine Advisers (MA) at Monterey and Santa Cruz, the north-south extremities of the bay, provided excellent data. Three sensors were installed within the harbor at Monterey and were in continuous operation from October 1963 to April 1964. Two were

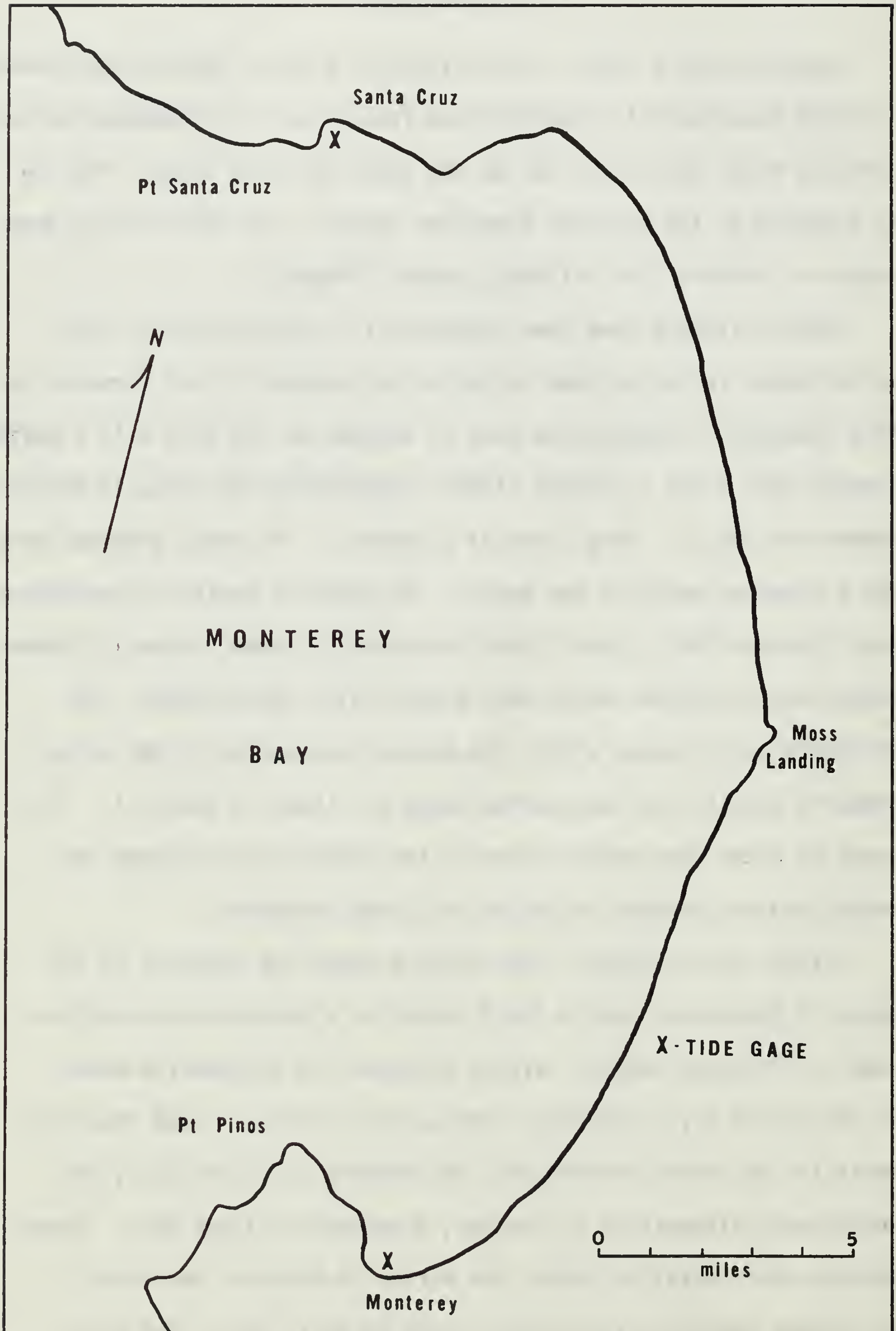

Santa Cruz
X
Pt Santa Cruz
N
MONTEREY
BAY
Moss
Landing
X - TIDE GAGE
Pt Pinos
X
Monterey
0
5
miles

FIGURE 1

arranged so that the tides and sea-swell were filtered out; a third recorded the sea-swell approaching the harbor. Wilson found no correlation between the long waves in the harbor and the approaching sea-swell. This finding led him to conclude that the surge in the harbor is not a result of the incoming swell or surf beat.

The MA sensor in Santa Cruz was inside the harbor, [Grauzinis, 1968]. Again, the short-period waves and swell were filtered out so that it functioned as a long-period wave recorder. This sensor was in continuous operation from October 1963 to February 1964. A summary of the Monterey and Santa Cruz data is presented in Tables II and III.

To obtain an independent evaluation of the oscillations in the bay, Wilson performed residuation analyses on several different records for various locations around the bay. Residuation analysis is accomplished by successively subtracting apparent periodicities from a wave record. The procedure is continued until a relatively smooth trace remains, and a sequence of apparent periods of oscillations is obtained. These results are presented in Table IV. Table V presents a synopsis of spectrum analyses for three days record of the Monterey MA sensors.

In order to determine the cause of the surge, Wilson made an extensive analysis of the two- and three-dimensional (i.e. two spatial and one time dimensions) oscillating characteristics of the bay using (1) approximate analytical solutions for a semi-enclosed basin, (2) numerical solutions for the modes of both two-dimensional and three dimensional oscillations, and (3) wave refraction diagram techniques.

He concluded, based on the best fit of the observed sequences of periods in Tables IV and V with calculated modes of oscillation for the bay, that the Monterey Submarine Canyon causes the bay to

TABLE I

Long-Period Waves in Monterey Harbor (after Hudson, 1949)

PERIOD (min)	AVERAGE HEIGHT (ft)	PERCENTAGE OF Time PRESENT
1-2	0.4	20
2-4	0.5	30
4-15	not given	15

TABLE II

Marine Adviser's Data for Monterey Harbor (after Wilson, 1965)

SENSOR	PERIOD (min)	AVERAGE HEIGHT (ft)	PERCENT OF TIME PRESENT
1	1.7-14	0.1-2.5	0-50
2	1-14	0.1-3.0	0-55

TABLE III

Marine Adviser's Data for Santa Cruz Harbor (after Wilson, 1965)

PERIOD (Min)	AVERAGE HEIGHT (ft)	PERCENT OF TIME PRESENT
1-2.3		0-18
2.3-4	0.2-2.0	20-70
10-14		0-25

DATE & TIME	SENSOR LOCATION	SEQUENCE OF APPARENT PERIODS - mins. or secs. (s)																
1400, Mar. 29, 1964 -0400, Mar. 30, 1964	Monterey Tide Gage	60	36.3	22.6		13.0	8.8		5.9									
March 29, 1964 0000-0900	Monterey Tide Gage	60	35.7 32.3	19.6	17.3	11.1	9.3		5.5									
Feb. 10, 1964	Monterey Sensor No. 1				17.1 (?)		8.6 (?)			3.8	2.5			1.00	42-45s			
	Monterey Sensor No. 2				17.2				5.7	4.1		1.95	1.20					
	Monterey Sensor No. 3											1.7			44.8s	23.4s	15.0s	9.3s 6.9s
March 12, 1965 0850-1000 1000-1100 1100-1200	Outside Municipal Wharf No. 2					13.5 12.1	8.4 8.4	6.1		4.6 4.4 4.2	2.3 2.8 2.9	1.6	1.30 1.32 1.35	0.98 1.00 0.90	42 s 36 s	24.0s 24.0s		
May 27, 1947 1148-1214	Moss Landing									3.9 4.1	2.5 2.2	1.96	1.25		50.1s 32 s 31 s			
June 2, 1947	Moss Landing									4.6	2.3		1.4		47 s		11.3s	7.8s
Nov. 24, 1964	Santa Cruz (1)	66	30	23.2		13.6 11.0		6.3										
	Santa Cruz (2)	86 (?)	28.5			13.0				3.6								

TABLE IV

Periods of Oscillation from Residuation Analysis (From Wilson, 1965)

Date	Monterey Sensor No.	Sequence of Periods (mins.)												
Case A Feb. 11, 1964	1		22.2		13.3	9.5	7.4		4.9	4.0		2.5	2.2	1.7
	2		22.2		13.3	9.5		6.1	5.0				2.2 2.0	1.8
	3		22.2		13.3	9.5			5.3	4.3	3.3 2.9	2.6	2.1 2.0	
Case B March 28, 1964 (tsunami)	1	33.3					8.3	5.8		4.3	3.2	2.4	2.0	
	2	33.3		16.7			8.3		5.3	4.4	3.3	2.5	2.3	
	3	33.3		16.7		9.5		6.1		4.3	3.5	2.4	2.1	
Case C April 12, 1964	1		22.2		13.3	9.5	7.4			3.9		2.6	2.2 2.0	1.9
	2		22.2		13.3			6.7	5.1	4.0	3.0	2.5	2.2	1.9
	3		22.2		13.3	9.5	7.4	6.1	5.1	4.0	3.2	2.4	2.2	1.9

TABLE V

Periods of Oscillation from Spectral Analysis (From Wilson, 1965) essentially act as independent north and south open-mouth oscillating basins with the boundaries lying along the natural mouth of the bay and the center line of the canyon. That is, oscillations in one end of the bay do not effect oscillations in the opposite end; the north-south basins are "uncoupled."

Raines [1967] analyzed twelve selected long-period wave trains from three years of tide data (1964-1966) obtained with the Naval Postgraduate School (NPS) recorder located on Municipal Wharf #2, Monterey harbor. Using graphical methods, he found mean periods of 19-39 min and 1.5-2.0 min. Raines did not rule out the possibility that the longer period waves were bay seiching, but he strongly suggested, based on his spectra and barometric oscillations occurring simultaneously with half of the wave trains analyzed, that the longer period waves were progressive waves produced by air-pressure fluctuations. Lack of adequate barometric pressure data precluded a correlation of the wave periods and air-pressure fluctuations. The shorter period waves were judged to be either harbor seiching or surf beat. This conclusion was based on the similarity of his results with those of Wilson [1965] and Hopper [1967] .

II. INSTRUMENTATION

The Monterey data for this study were obtained with a standard Coast and Geodetic Survey automatic tide gage [Manual of Tide Observations, 1965] . The gage, which is maintained daily by NPS personnel, is located on Municipal Wharf #2, Monterey harbor.

This instrument senses changes in water level by means of a float/pulley arrangement. The recording drum is advanced by a clock mechanism. The drum speed is designed to be 1 in/hr but the NPS gage has an hourly feed of approximately 1.06 in/hr. The marigram is recorded in rectilinear coordinates on plain white paper. The majority of higher frequency wind waves (periods of 4 min and below) are filtered by a stilling well which is a 12-in diameter steel pipe with a 1-in orfice in the bottom.

The Santa Cruz data were obtained with a Bristol Model 28 gas-purging pressure (bubbler), portable tide gage located on the Santa Cruz wharf. This instrument senses changes in water level by means of a nitrogen-filled tube which is connected to a bellows system [Manual of Tide Observations, 1965] . The marigram is recorded on a mechanical-clock strip-chart recorder in curvilinear coordinates. The design chart drive speed is 1 in/hr, but a substitution of drive gears increased this to 6 in/hr

A bubbler orfice chamber was connected to the end of the sensing tube to reduce wave action. There was also a bellows inlet needle valve which could be throttled to further filter wave action from the record. The combination of these two filtering mechanisms proved inadequate. A stilling well was designed and installed to attain the desired filtering of high frequency wind waves. The well was constructed of a 20-ft section of polyvinyl Chloride (pvc) 6-in inside-diameter pipe. The well was capped and 16, 1/4-in inside-diameter holes drilled in the side. Copper sleeves were inserted to eliminate fouling. The 16 holes provided the capability of increasing the orfice from a 1/4-in to a 1-in diameter opening.

The response characteristics of the well were determined theoretically for two orfice sizes and three different wave frequencies using the equation for the rate of water rise in a well [Doodson and Warburg, 1941] :

$$\text{rate of rise of water in well} = dh_i/dt = 0.6\ a/A \sqrt{2g(h_o - h_i)}$$

where

a = orfice area
A = well area
0.6= empirical orfice flow coefficient
g = acceleration due to gravity
h_o = water height outside the well, i.e. the forcing function
h_i = water height inside the well.

The forcing function, h_o, was chosen to be a simple sine function of unit amplitude and frequency equal to the wave frequency of interest. The initial conditions were $h_i = 0$ at $t=0$. The results are summarized in Table VI.

The response characteristics for the Monterey stilling well were not calculated since the orfice area to well area ratio is larger, providing response characteristics better than those of the Santa Cruz well. A 1/4-in orfice was used in the Santa Cruz well.

PERIOD	ORFICE DIAMETER (in)	PHASE LAG (deg)	AMPLITUDE REDUCTION (%)
20 sec	0.25	180	95
20 sec	1.00	72	45
60 sec	0.25	75	91
60 sec	1.00	30	5
25 min	0.25	6	1
25 min	1.00	0	0

TABLE VI

Computed Response Characteristics
of Santa Cruz Stilling Well

III. DATA ANALYSIS

A. SELECTION OF DATA

Because this study was concerned with the character of seiching motions affecting the entire bay (and not their frequency of occurrence), only those records with similar long-period wave characteristics at each station for equal intervals were considered for analysis. Also, the seiching had to persist long enough to provide an adequate number of data points for a meaningful analysis. The minimum persistence time considered was ten hours. Two days were selected which met these criteria; 23 January and 20 April, 1969.

The Santa Cruz marigram for 23 January was recorded at a rate of 1 in/hr with a 20-ft range instrument. Although the stilling well had not been installed, the trace was relatively narrow and free of wind-wave noise. The long-period waves lasted for approximately 15 hours (1000 23 January - 0100 24 January).

The Santa Cruz marigram for 20 April was recorded at a rate of 6 in/hr with a 10-ft range instrument. The stilling well had been installed by this date. (In February, the 10-ft range instrument was substituted to improve the resolution of the record and the recording rate was increased to facilitate digitizing procedures.) The long-period waves for this day lasted approximately 10 hours (1100-2100 20 April).

B. DIGITIZING PROCEDURE FOR MONTEREY DATA

The Monterey record, a rectilinear trace, was digitized using a Calma Co. Model 480 mechanical digitizer (Appendix A). The sampling rate, Δt, for the 23 January record was 33.87 sec whereas the sampling rate for the 20 April record was 33.77 sec. The difference in sampling rates was not due to the digitizer, which had a constant sampling interval of 0.01 in, but rather was a result of the different recording rates of the two records. The average recording rates were 1.063 in/hr and 1.066 in/hr for the 23 January and 20 April records respectively.

C. DIGITIZING PROCEDURE FOR SANTA CRUZ DATA

The Santa Cruz records were not digitized by the machine method because of the problems encountered in digitizing a curvilinear record with a rectilinear device. A simple geometrical relationship can be used to convert the rectilinear digitized data of a curvilinear record, but this conversion introduces errors and high frequency noise [Steele, 1967] which were thought to be excessive for this study. These records were, therefore, digitized by hand. It was not possible to equal the Monterey data sampling interval of 0.01 in for the 23 January Santa Cruz record since the latter was recorded at 1 in/hr. A sampling interval of approximately 0.025 in was used, giving a sampling rate of 89.64 sec. This meant that the sampling rate for the Monterey record was about two and one-half times better than the Santa Cruz record for this date.

The sampling interval for the 20 April record, a 6-in/hr recording rate, was selected to be as close as possible to that for the Monterey record. The resulting sampling rate was 33.14 sec, approximately one-half second slower than that for the Monterey record.

The problem, and avoidance, of aliasing in spectral analysis of a finite, discrete, record is thoroughly discussed in the literature. It is only important to note here that the sampling rates achieved in this study are more than adequate since both tide gages are long-period recorders designed to filter out all waves with periods below 4 min. Aliasing, therefore, is not considered a problem and is not discussed below.

D. ANALYSIS

Before the data were analyzed, it was necessary to remove the trend due to tidal components. The detrending was accomplished to an adequate degree by forming a pure cosine curve, η_i, which closely approximated the tidal record for the specific interval digitized, and subtracting this "tidal curve" from the raw data, y_i. That is,

$$\eta_i = A\cos(2\pi f i \Delta t - \theta) \qquad i=1,2,3,\ldots,N$$

where

A = amplitude measured on marigram
f = tidal frequency measured on marigram
θ = appropriate phase lag required to match data and η_i
N = number of data points,

and

$$Y_i = y_i - (m + \eta_i) \qquad i=1,2,3,\ldots,N$$

where m is the mean measured on the marigram and Y is the detrended data.

The Fourier coefficients of the detrended data were calculated using the IBM/360 library subroutine RHARM. This subroutine is a one-dimensional fast Fourier transform (FFT) analysis based on the Cooley and Tukey [1965] algorithm. The program is designed to analyze N data points where

$$N = 2^m \qquad m = 3,4,5,\ldots,20.$$

The FFT not only greatly reduces the number of calculations from earlier Fourier analysis schemes, but also reduces the round-off errors in the coefficients. Specifically, both the number of computations and round-off errors are reduced by essentially $\log_2(N)/N$ [Cochran, et al, 1967]. Before the spectrum was formed, each Fourier coefficient was hanned.

The raw Fourier transform is exact for the specific frequencies of the calculated coefficients. Adding, however, a term of the form Dcos(ft) where the frequency f is not one of the discrete frequencies, f_i, will alter all the Fourier coefficients in the time series. This is, in effect, an energy leakage into the discrete frequencies of the raw periodogram. Leakage can be defined as the altering of a spectral estimate for a specific bandwidth by the energy at more or less random frequencies outside the bandwidth of interest. The effects of leakage in the raw periodogram decay as $1/|f-f_i|$ as f_i recedes from f. Hanning the coefficients before forming the spectrum increases the decay to $1/|f-f_i|^3$ [Bingham, et al, 1967]. If a_i and b_i are the raw Fourier coefficients, the hanned or modified coefficients are formed using:

$$A_k = -(1/4)a_{k-1} + (1/2)a_k - (1/4)a_{k+1}$$

$$B_k = -(1/4)b_{k-1} + (1/2)b_k - (1/4)b_{k+1}$$

The spectral estimates, $(A_k^2 + B_k^2)$, k=1,2,3,...,N/2, were normalized by multiplying each by the time interval analyzed.

Figures 17-22 (Appendix B) are the computed spectra for the two days analyzed. The 15-hr period wave activity on 23 January is depicted by two, overlapping spectra for each station. This is a consequence of the RHARM restrictions on the number of data points.

The spectra are not the entire spectra, but rather only the low frequency portion. The dashed line on the low end of the spectrum indicates that all energy in the tidal components has not been removed. Similarly, the dashed line at the higher end of the spectrum designates the start of the high-frequency noise. There is approximately three hours difference in the Monterey and Santa Cruz time intervals for the spectra for 23 January, which is a consequence of the number of data points and the unequal sampling rates.

The spectra for different stations on the same day show a certain amount of correspondence with each other, but it is difficult to match periods of oscillation between spectra since it is not easy to determine with confidence which peaks in the spectra are spurious and which are real.

Spectral estimates of a random process have a chi-squared distribution [Bartlett, 1955] and are inconsistent estimates of the power spectrum. Each coefficient has 2 degrees of freedom, and the confidence in each spectral estimate can be increased by (1) averaging spectral estimates over a span of frequencies or (2) "blocking" the record, analyzing each block and averaging spectral estimates at equal frequencies [Jones, 1965; Hinich and Clay, 1968].

The spectra in this study were averaged over three bandwidths. Smoothing the spectra in this manner gives more confidence in the true peaks, but the resolution in each spectrum is simultaneously degraded. The two spectra for each station on 23 January have been averaged together at equal frequencies to give a spectrum for the entire 15-hr period.

When sequentially averaging over three bandwidths, there are three possible starting points, that is, three possible methods.

The spectra were averaged for all three possibilities which permitted determination of the resolution and stability of each peak. Schematic representations of the smoothed spectra are presented in Figures 2-5. These spectra represent a compilation of the three averaging methods for each spectrum. Only those peaks which were stable in shape and energy density are labeled with the bandwidth resolution. All peaks not labeled will not be considered further.

Spectra for 10-hr periods both before and after the long-period wave activity on 23 January and 20 April were also calculated for each station (Figures 23-30, Appendix B). These spectra were smoothed in the same manner described above. Schematics of the "before" and "after" spectra for each station are presented in Figures 6-9.

The original intention in this study was to compute the cross-spectra for the Monterey-Santa Cruz records. It was hoped that, with the cross-spectral values and average phase lags for each discrete frequency, a thorough understanding of the seiching motions in Monterey Bay could be obtained. The cross-spectra calculations were not feasible, however, for two reasons.

The records were not accurately synchronized. It is estimated that an initial time difference of as much as 3 min between the two records could be present. This was due to the variability in the seperate gage clocks and the maintenance of the gages by different persons at varying intervals. This factor alone is not prohibitive since Grauzinis [1968] has outlined a procedure for computing cross-spectra for records without initial synchronization. A more serious error was created by the unequal digitizing rates between records from the two stations. A cumulative phase error was introduced by sampling at unequal rates. The data obtained in this study, therefore, are considered unsuitable for cross-spectral analysis.

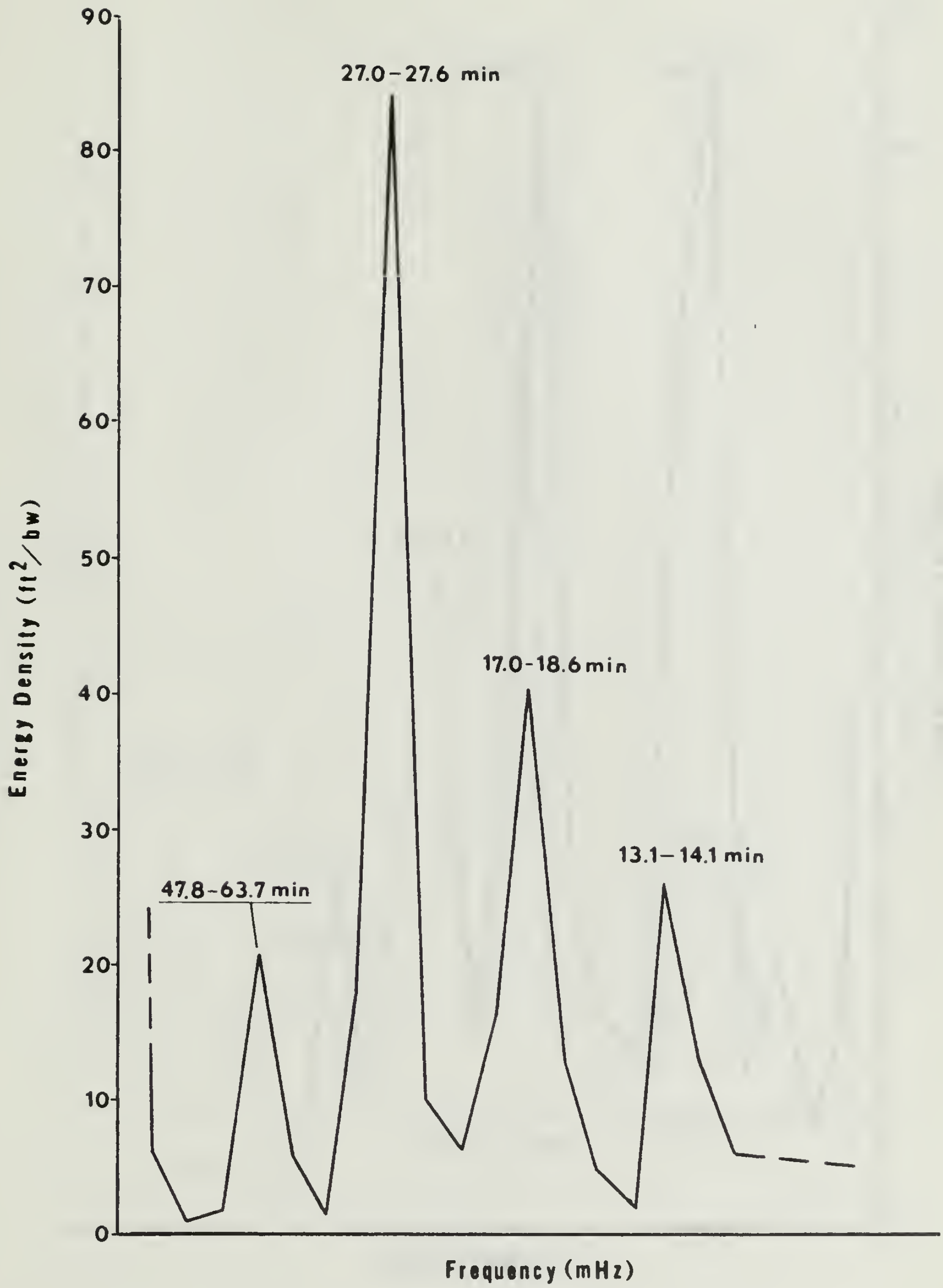


Figure 2

Smoothed Spectrum for Santa Cruz - 1000 23 January to 0100 24 January

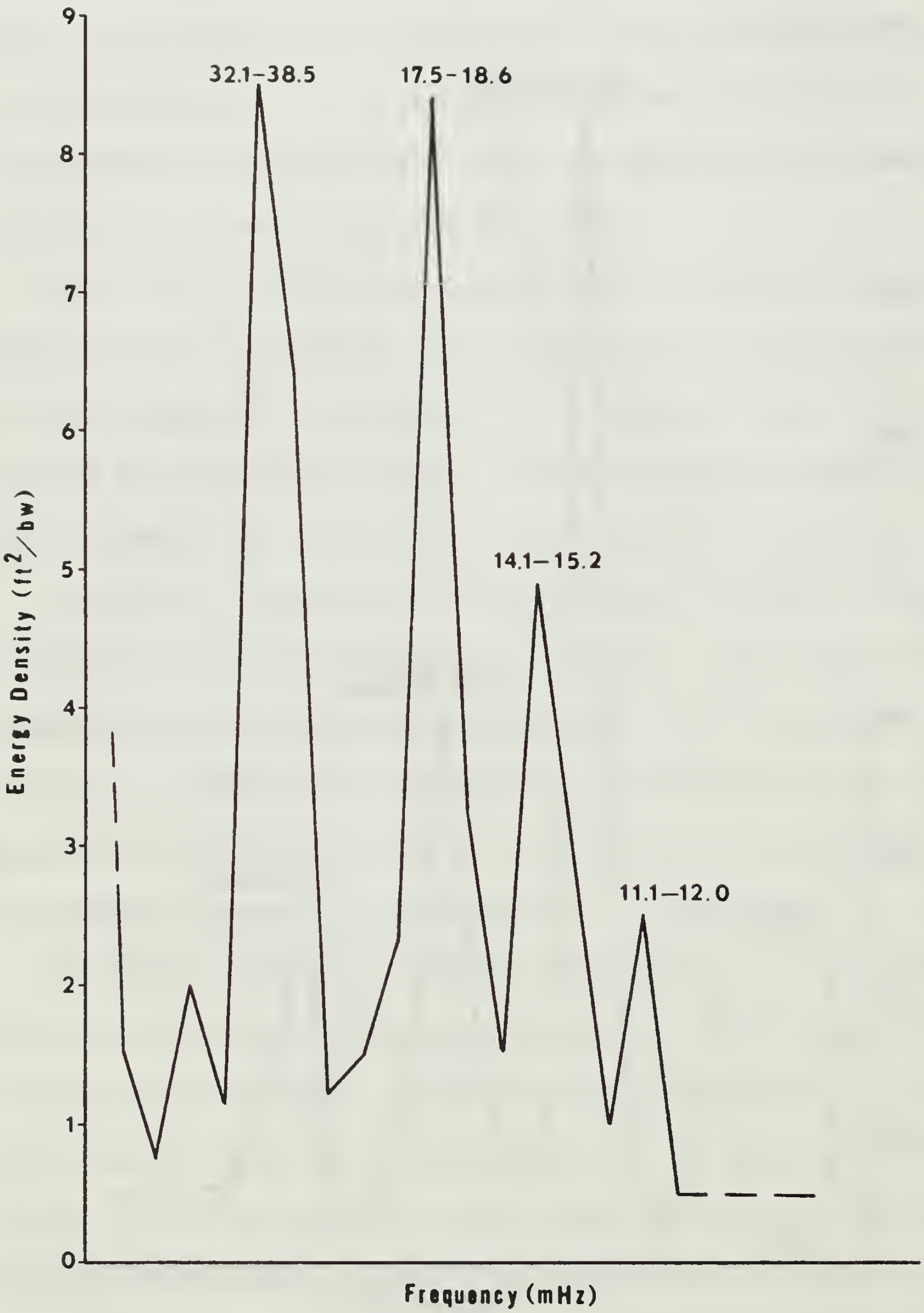


Figure 3

Smoothed Spectrum for Monterey - 1000 23 January to 0100 24 January

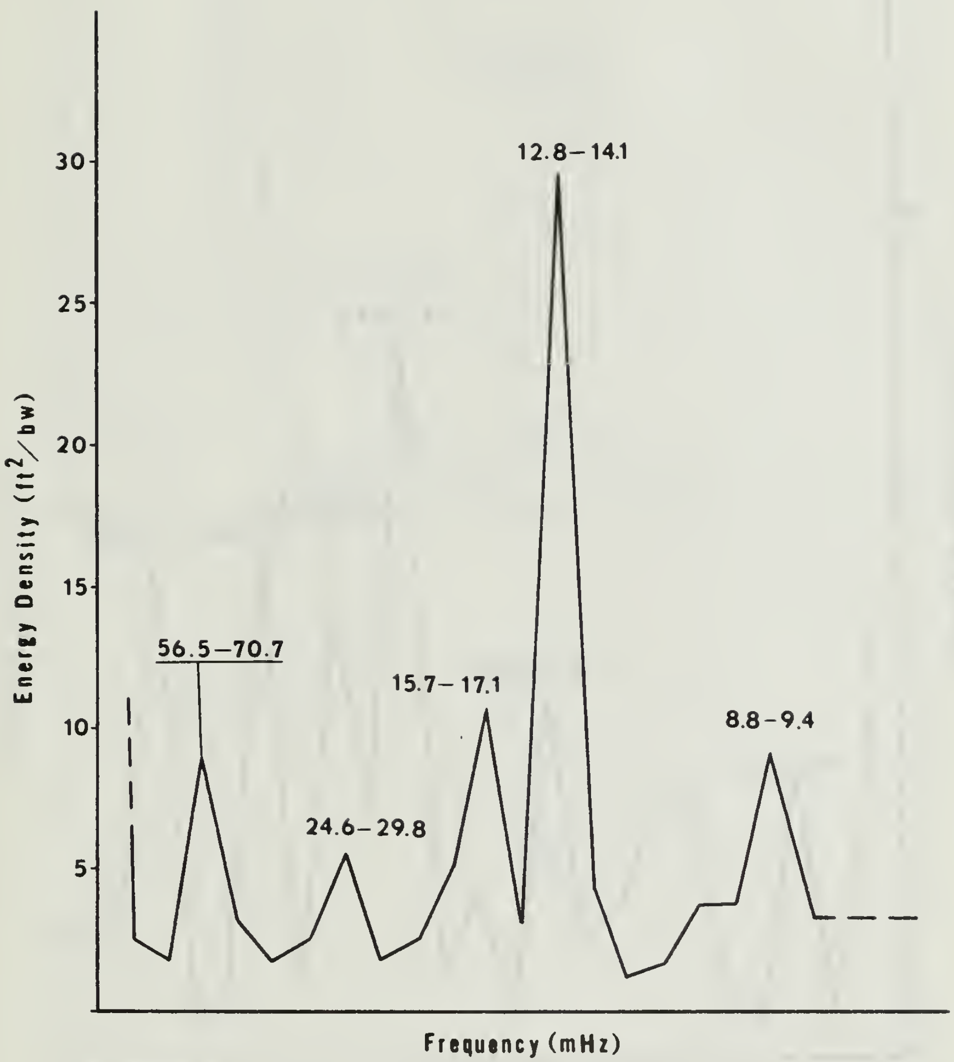


Figure 4

Smoothed Spectrum for Santa Cruz -1100 20 April to 2058 20 April

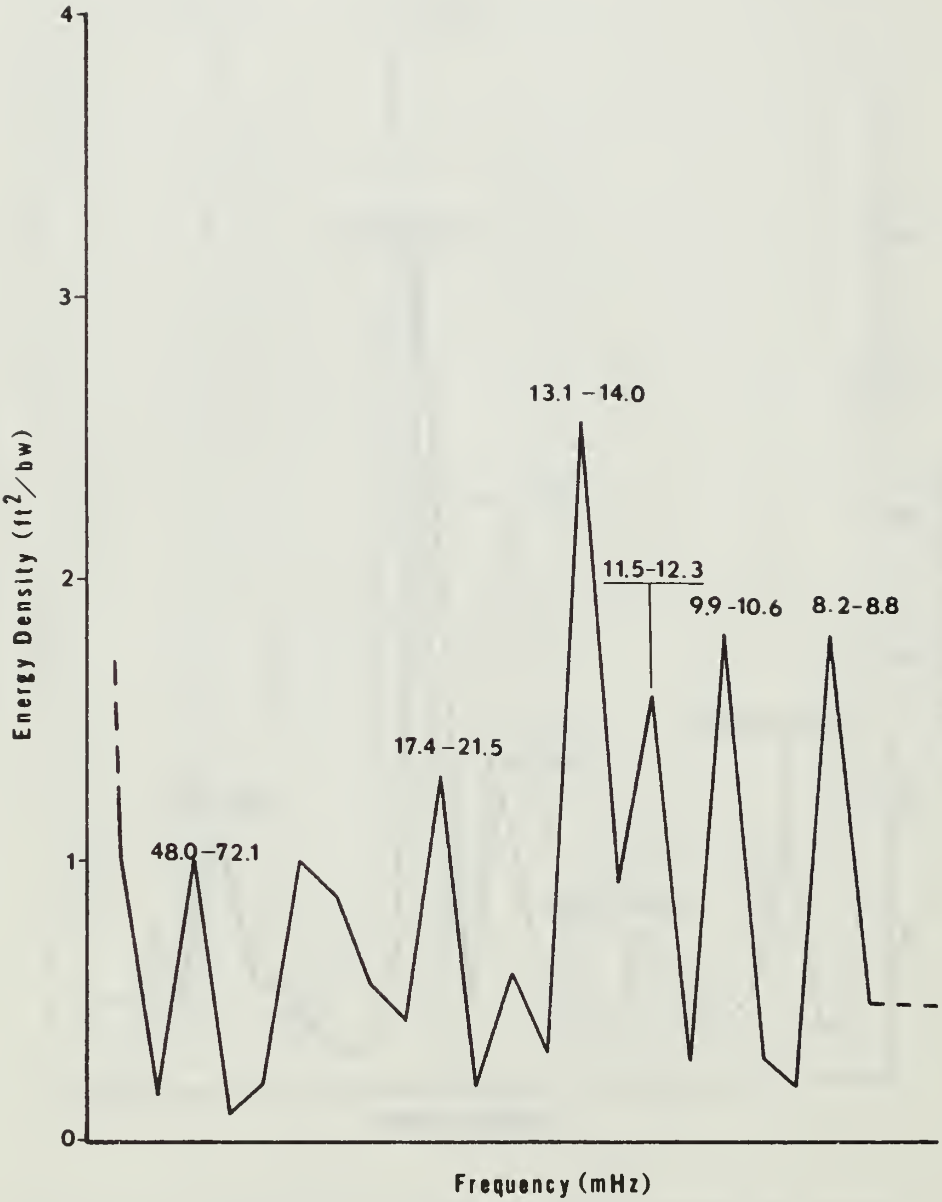


Figure 5

Smoothed Spectrum for Monterey - 1100 20 April to 2048 20 April

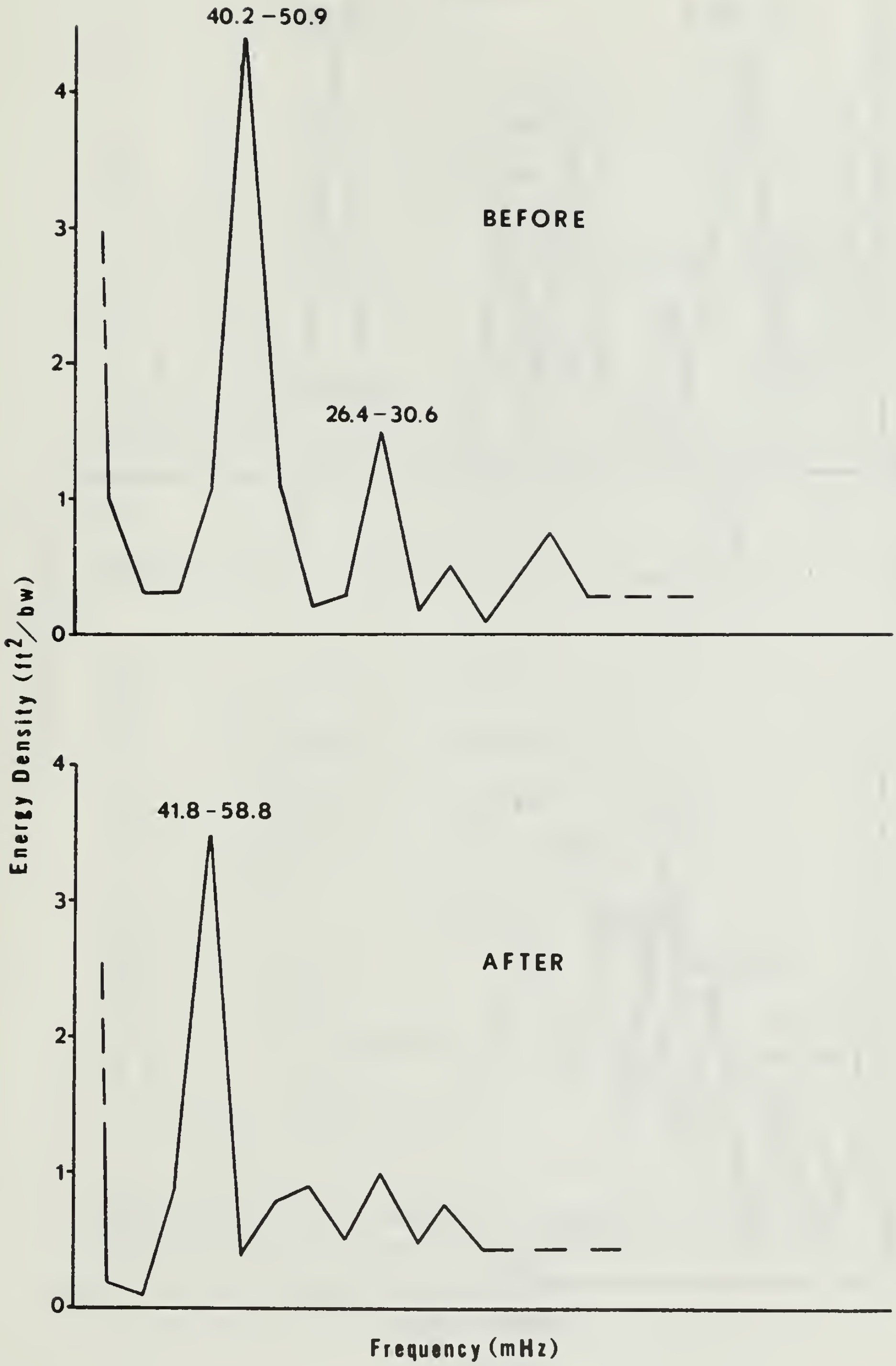


Figure 6

Smoothed Santa Cruz Before/After Spectra - 23 January

Figure 7

Smoothed Monterey Before/After Spectra - 23 January

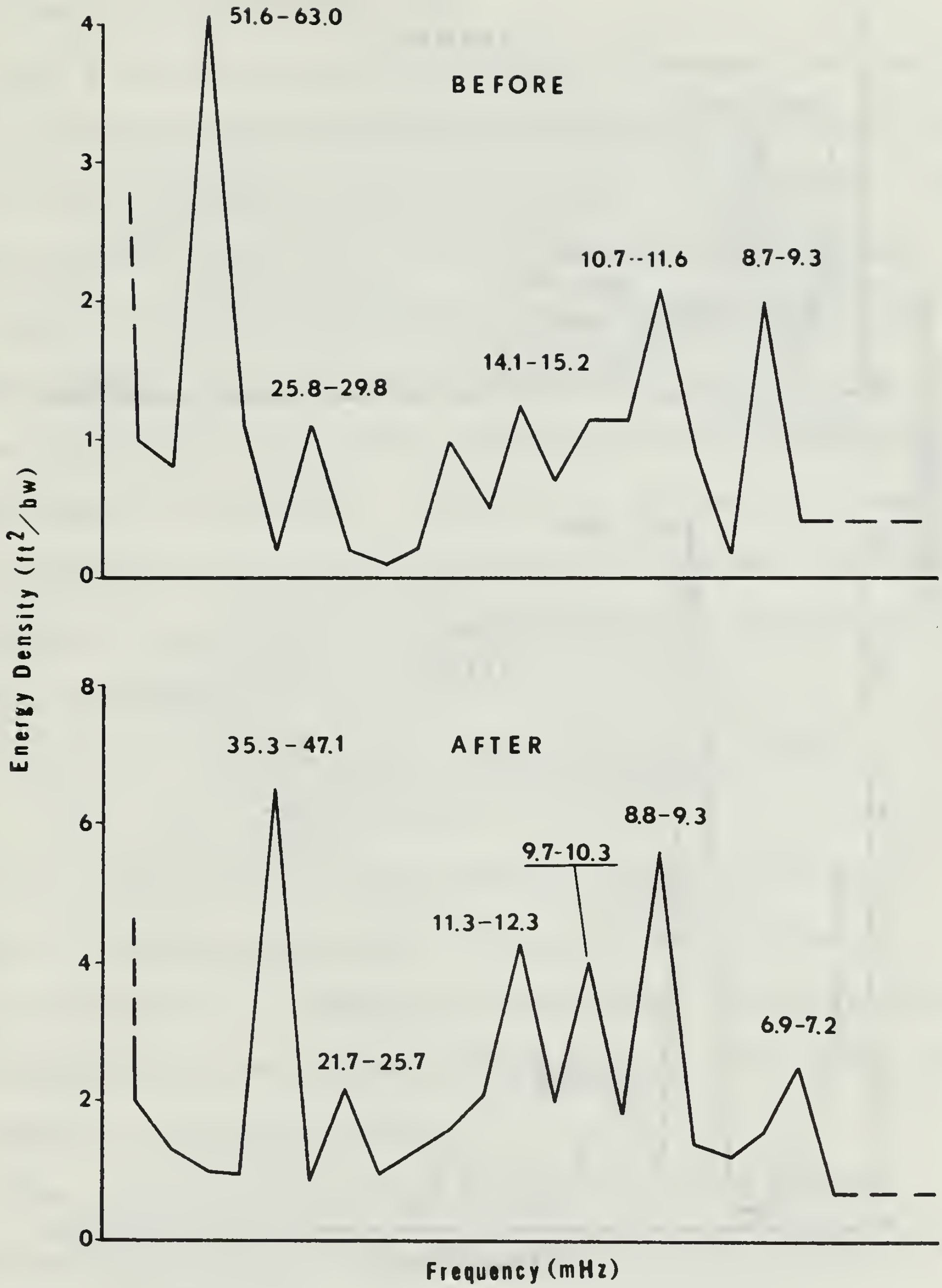


Figure 8

Smoothed Santa Cruz Before/After Spectra - 20 April

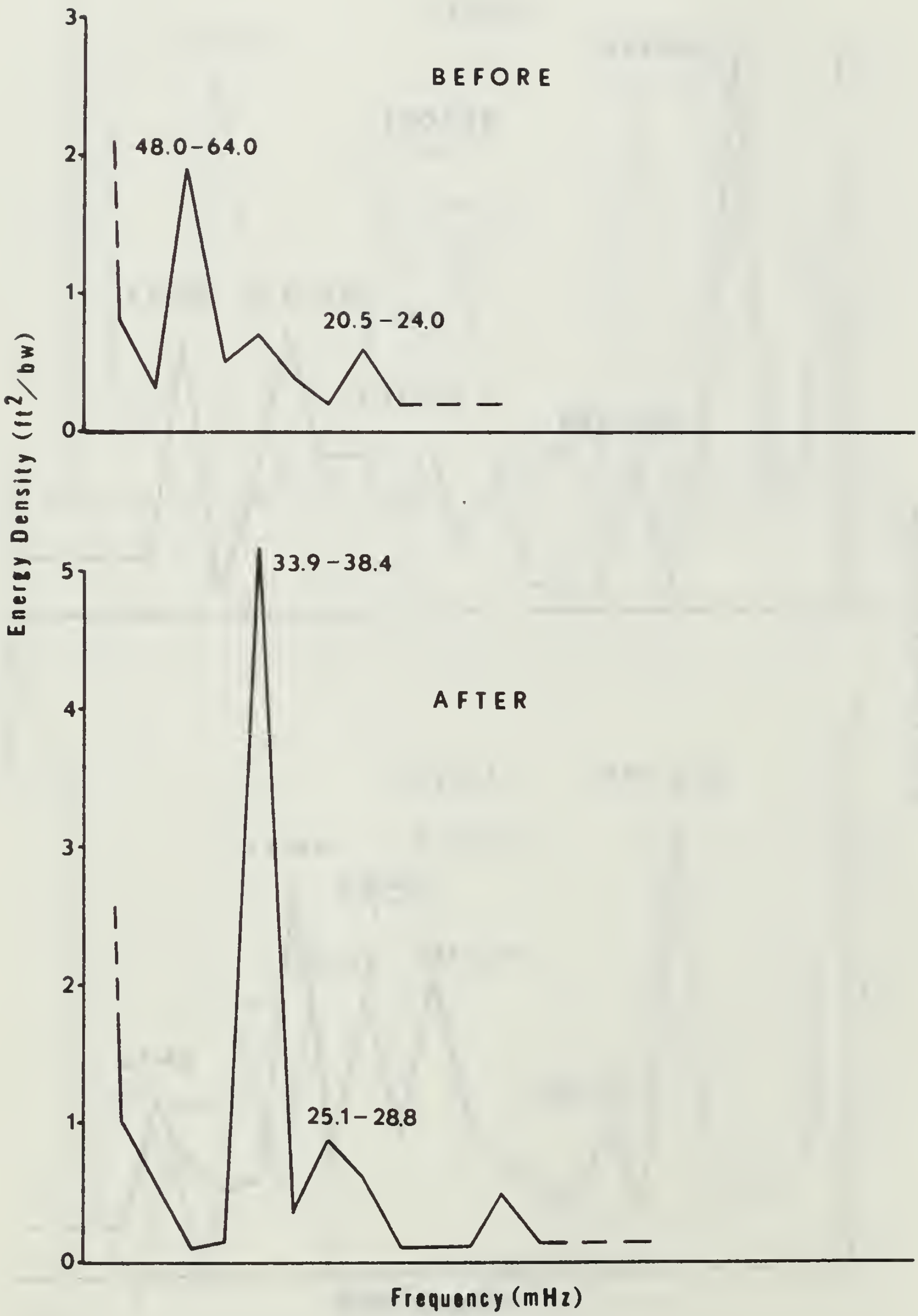


Figure 9

Smoothed Monterey Before/After Spectra - 20 April

IV. DISCUSSION

A. WILSON'S THREE-DIMENSIONAL MODEL

Wilson's numerical calculations for the three-dimensional oscillating characteristics of Monterey Bay are depicted in Figures 10-13. Figure 10(a) illustrates the grid points used for the solution. The numbers adjacent to each grid point are the water depths in feet. The dashed line connecting Point Santa Cruz with Point Pinos is the assumed boundary nodal line for the solution.

The successive figures depict decreasing periods (increasingly complex modes) of oscillation. The contours are water level amplitudes normalized to the highest anti-node for the mode. The inset to the left of each figure is a simplified modal oscillation. The sequence of periods is

$$T_n = 44.2, 29.6, 28.2, 23.3, 21.6, 20.4, 19.4, 18.7, 17.6, \ldots, 13.3, \ldots, 12.4, \ldots \text{min.}$$

Wilson notes that the assumed boundary nodal position could very well be incorrect and might be more to seaward, closer to the 100-fathom curve. Changing the assumed nodal line would alter the boundary conditions and would affect both the modal periods and the geometry of the oscillations.

Modes 1 and 2 indicate strong oscillations in the northern portion of the bay and little effect in the southern portion of the bay. Mode 3 shows the first strong oscillation in the southern portion. Mode 4 indicates similar oscillations at both the northern and southern ends with weak oscillations over the canyon. Successive modes become more complex.

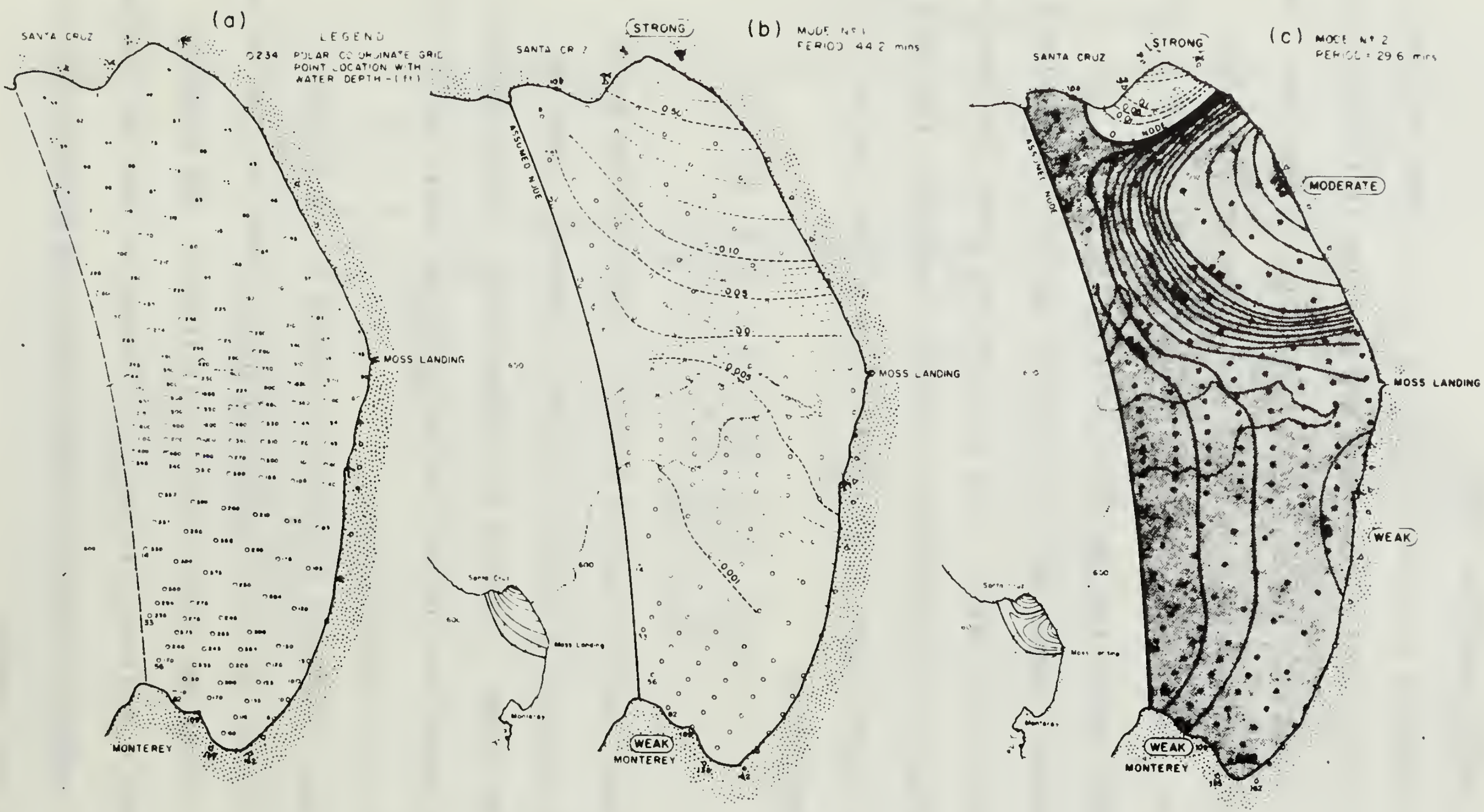


Figure 10

Numerical Calculations of Modes of Oscillation of
Monterey Bay (from Wilson, 1965)

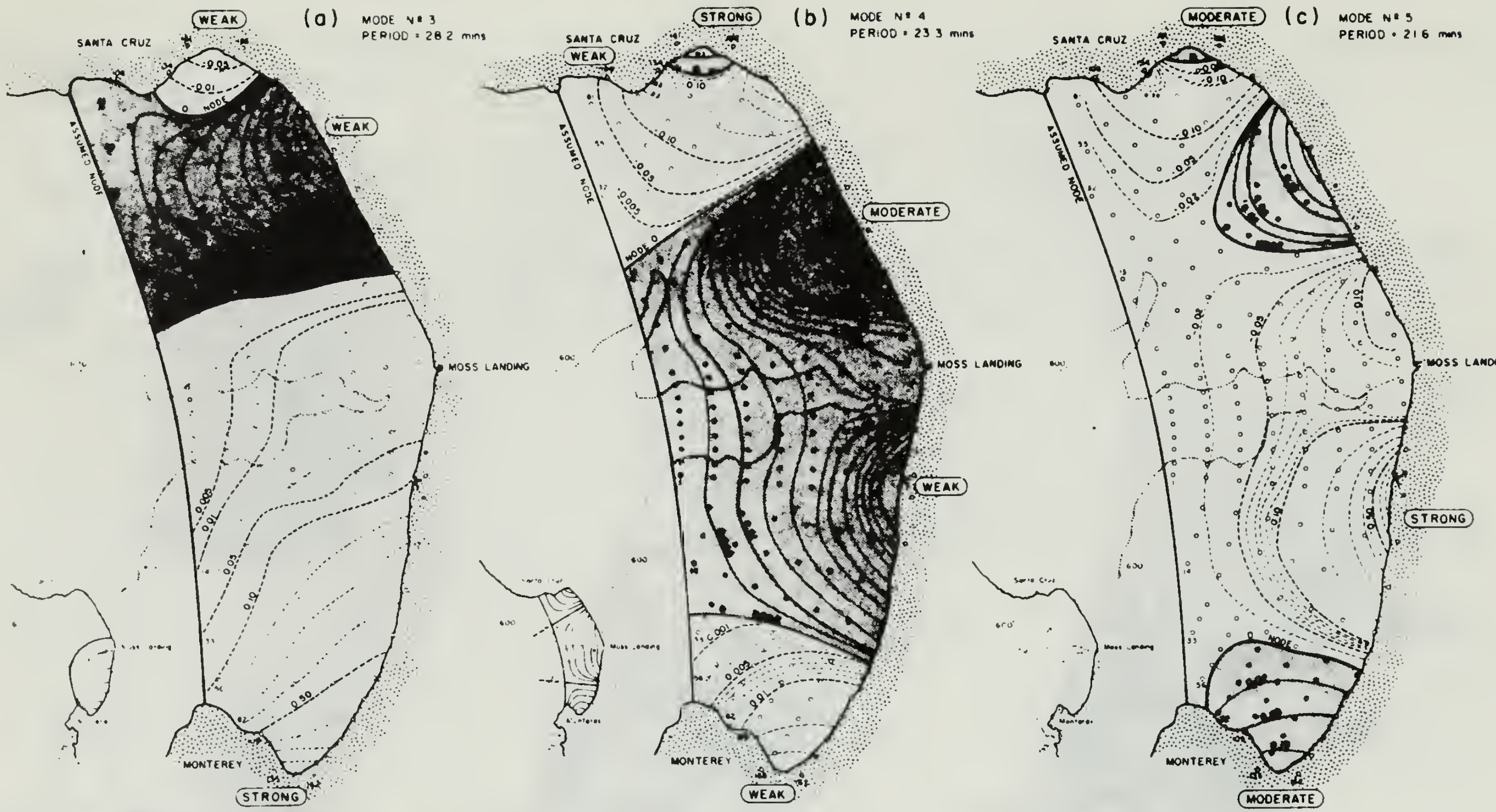


Figure 11

Numerical Calculations of Modes of Oscillation of Monterey Bay (from Wilson, 1965)

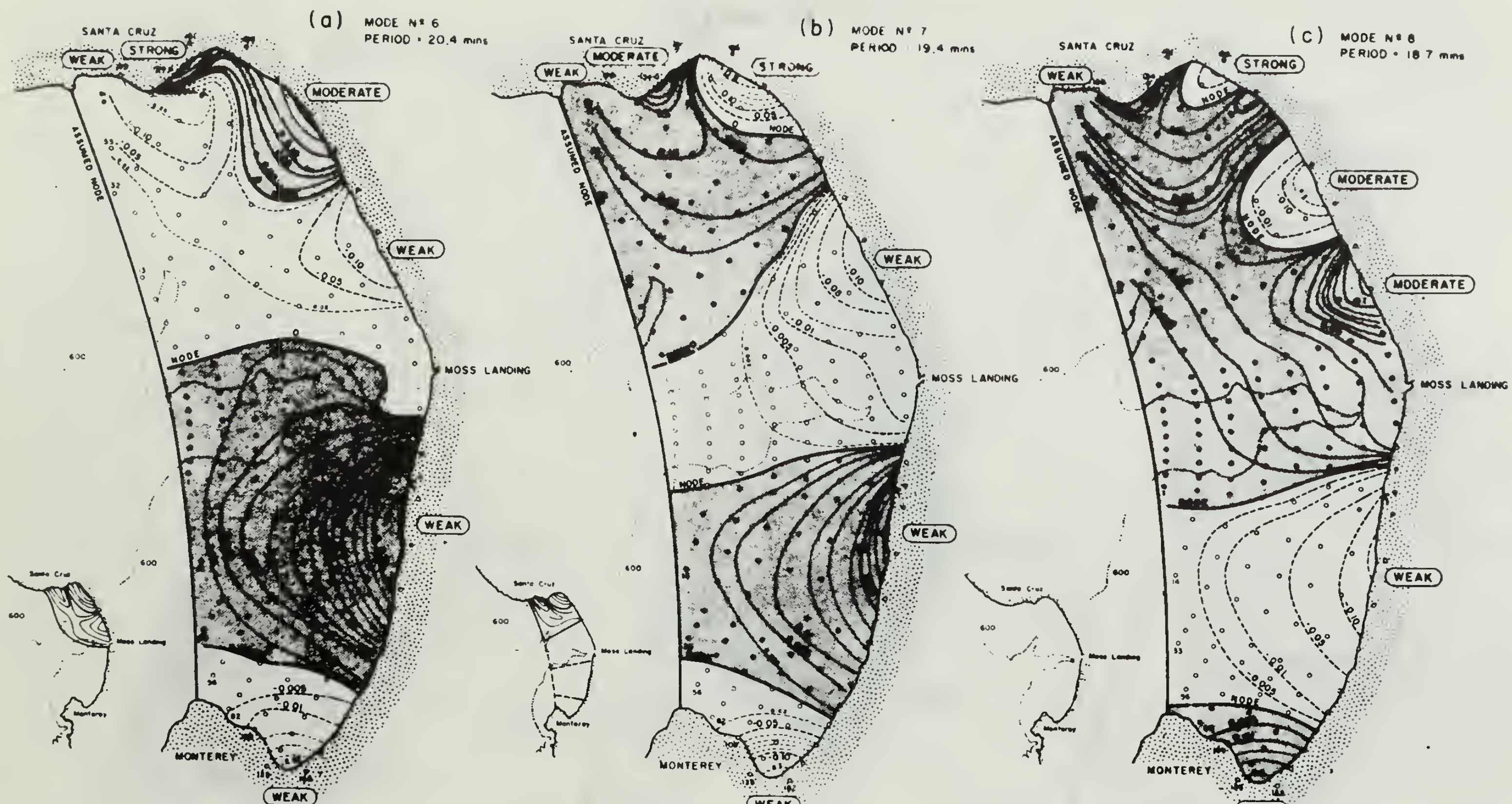


Figure 12

Numerical Calculations of Modes of Oscillation of Monterey Bay (from Wilson, 1965)

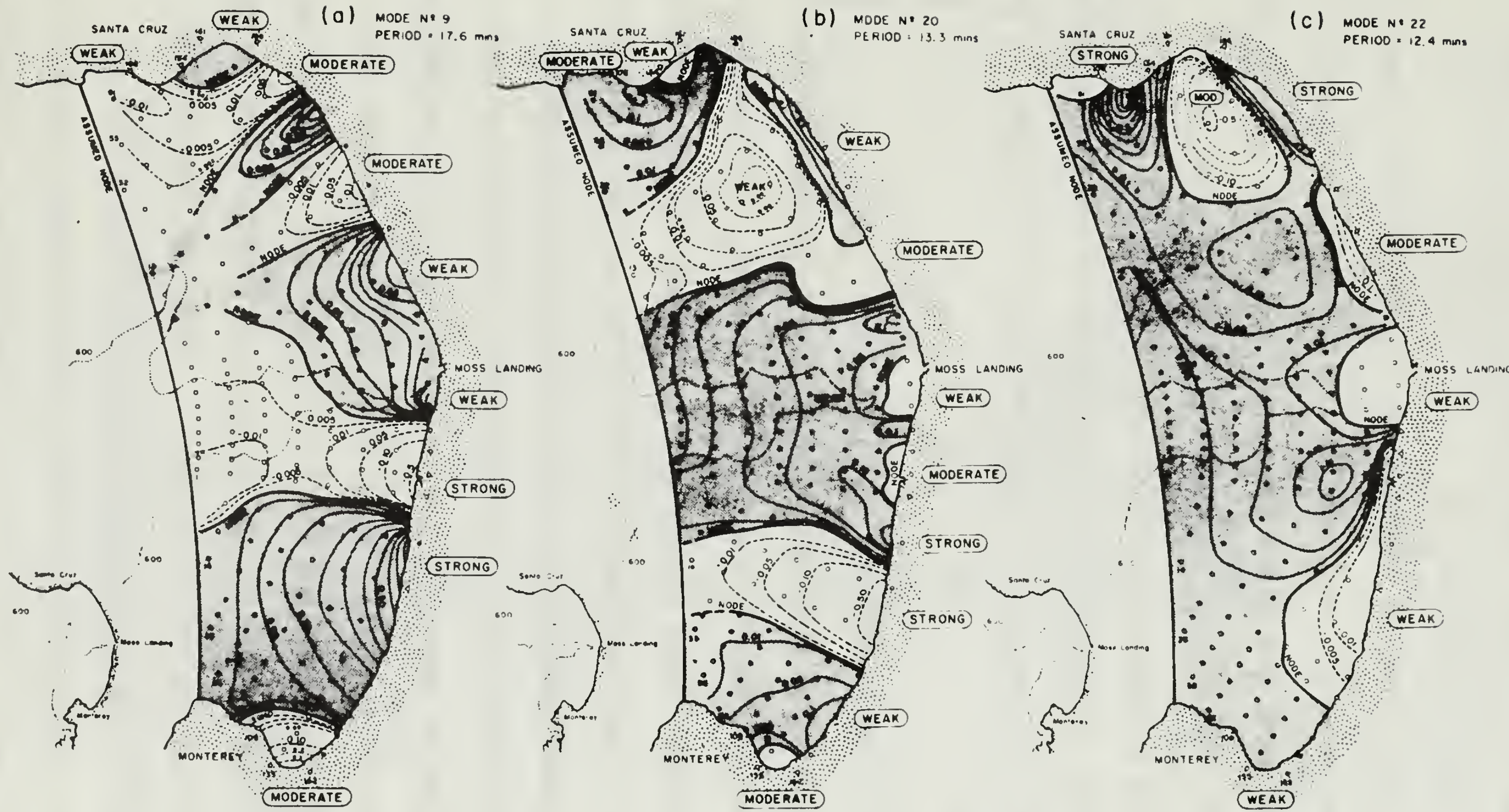


Figure 13

Numerical Calculations of Modes of Oscillation of Monterey Bay (from Wilson, 1965)

Wilson does not state the highest mode in which he has confidence, but he does note that errors will increase in any eigenvalue problem as the mode number increases. This increasing error can be slowed by choosing a finer grid system.

Wilson argued that his observations (Tables IV and V) tend to confirm his computations. Note that for modes exhibiting strong oscillations in only one end of the bay, amplitudes in the oscillating end are 10 to 100 times larger than amplitudes at the opposite end. (Only modes 7,8, and 20 show nearly equal amplitudes at the bay extremities.) This led Wilson to conclude that oscillations in one end of the bay have no effect on, and occur independently of, oscillations in the opposite end.

B. INTERPRETATION OF SPECTRA

There are several obvious statements which can be made about the smoothed "before", "during", and "after" spectra. For ease in comparing the energy levels of the various spectra, all the spectra for the same day at both stations are plotted to the same scale in Figures 14 and 15. These schematics show only the smoothed energy peaks.

The energy levels for the during spectra are always higher at Santa Cruz than at Monterey, but the energy levels for the before/after spectra for both stations on both days are the same. The energy levels for the during spectra at Santa Cruz are much greater (23 January) and greater (20 April) than the energy levels in the before/after spectra for Santa Cruz. In Monterey, however, the energy levels in the during spectra are only slightly more (23 January) and slightly less (20 April) than the energy levels in the before/after specta. No convincing explanation can be offered for these differences.

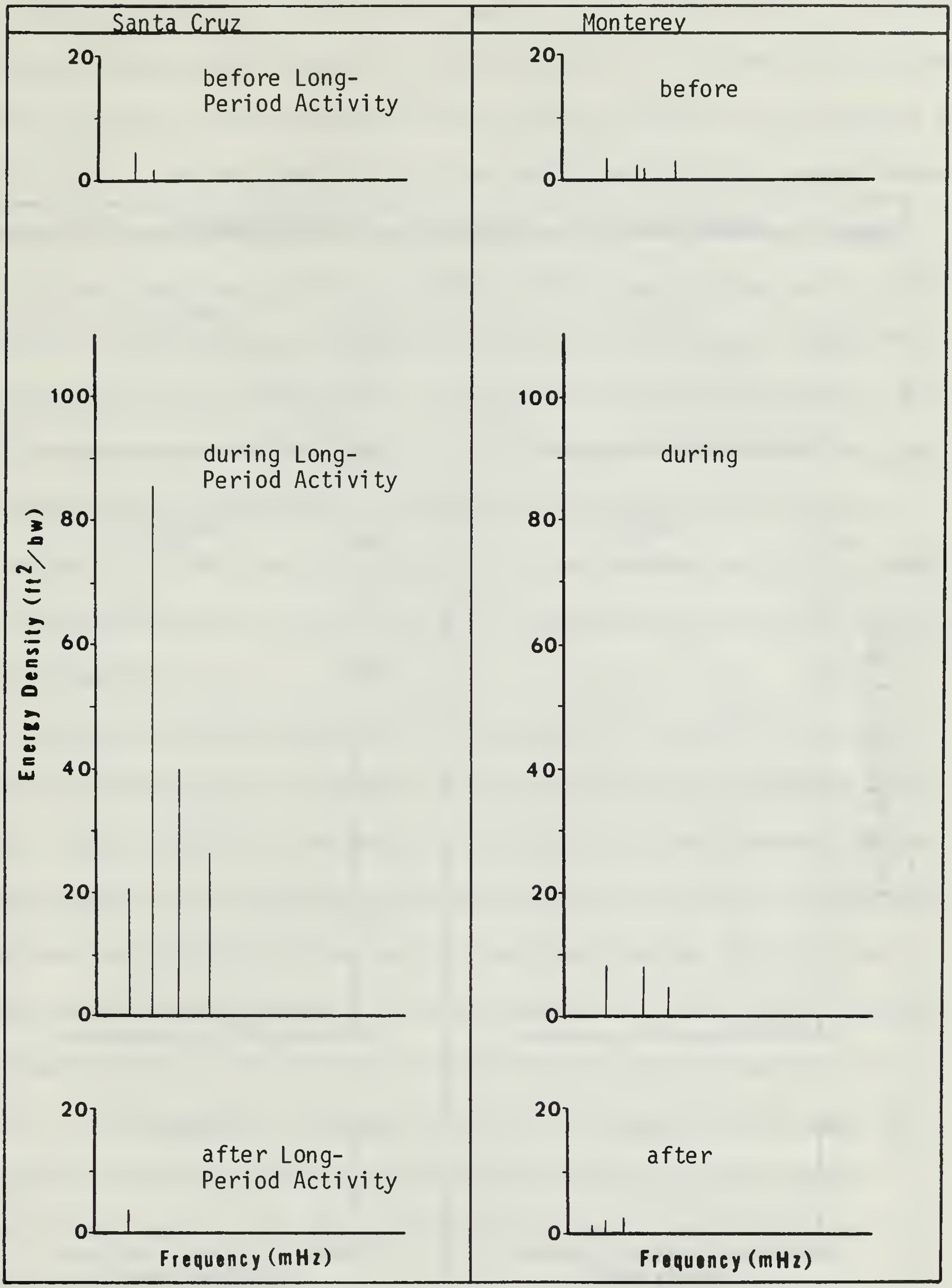


FIGURE 14

Schematic Representation of Spectra for 23 January
Santa Cruz and Monterey

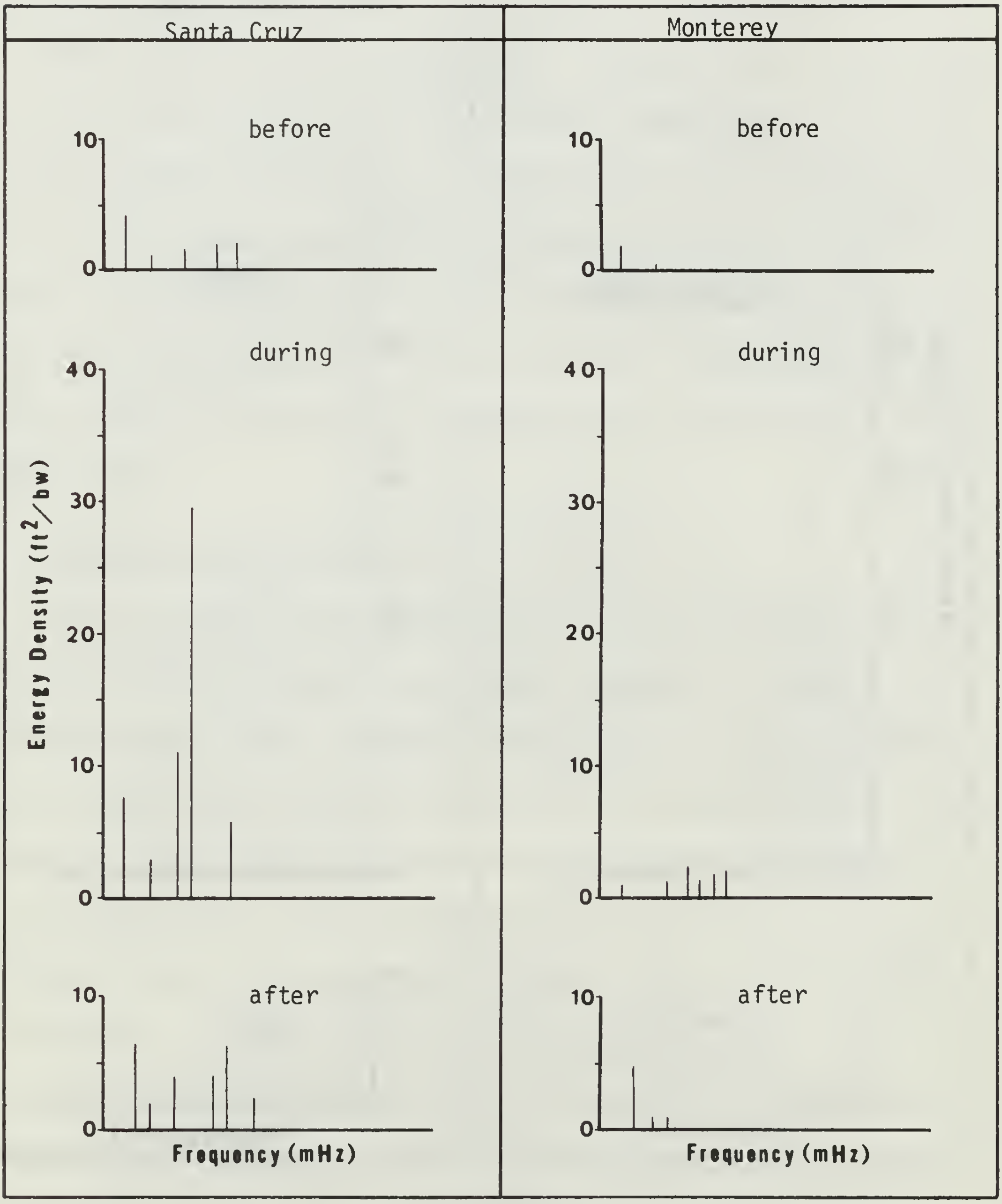


FIGURE 15

Schematic Representation of Spectra for 20 April
Santa Cruz and Monterey

There is evidence in the during spectra that 16-18, 13-15, and 45-60 min oscillations were present at both stations for the two days analyzed. About 10 other spectra for each station were calculated in the course of this study. The 16-18 min oscillations were consistently present whereas the 13-15 min oscillations were usually, but not always, present.

The before/after spectra all exhibit some type of long-period wave activity. Most show oscillations in the 45-60 min range. There does not seem to be any correspondence between the before/after spectra for different stations on the same day. It is possible, for some periods, to detect signs of build-up and decay in the before/after spectra at a station. On the other hand, there are some periods which are present in only the before or only in the after spectrum and not present in the during spectrum.

Before attempting to analyze the spectra, it is well to ask if the long-period waves on 23 January and 20 April were seiching in the bay. Unfortunately, it is impossible to tell by simply examining the power spectra. An accurate determination could be made if the records had been accurately synchronized so that phase angles for each frequency could be calculated or if data from an off-shore recorder were available so that the off-shore and near-shore spectra could be compared. Without this information, however, one can only say that the two most distinct possibilities for waves in this frequency range are (1) bay seiching or (2) shelf oscillations in the vicinity of the recording instruments.

Wilson's model for seiching in Monterey Bay predicts greatly different amplitudes at the extremities of the bay, but of course the periods of oscillation are the same over the entire bay. Munk [1962] found shelf oscillations ranging in period from 2.5 min to 3.1 hr.

These oscillations are determined by the dimensions of the continental shelf and extend from the shelf edge to the shoreline. The oscillations might be quite localized with different periods of oscillation for relatively near points along a coast. Munk notes that shelf oscillations can radically shape the spectrum of a record measured near shore, since the anti-node is at the shoreline. It is possible that bay seiching and shelf oscillations can occur at the same time. The record from an offshore recorder would be invaluable in defining the periods of shelf oscillations.

Notice for the 23 January spectra that Santa Cruz has a strong oscillation at 27.0-27.6 min and Monterey has a strong oscillation at 32.1-38.5 min. These two oscillations are not repeated on the 20 April spectra. It could be argued that these are localized shelf oscillations as found by Munk. It could also be argued, however, that these are periods of bay seiching and that the amplitudes of these periods were so small on the opposite end of the bay that they did not show in the spectral analysis, as predicted by Wilson's model. Several other periods of oscillation in the spectra can be treated in the same manner as this, but they are not as pronounced as these two. However, it is not possible to take every peak in the spectra for 23 January and 20 April and state that they are evidence of bay seiching.

It is more reasonable to look for periods of oscillation which are evident at both stations on both days analyzed. If these occur and have similar amplitude ratios on the two seperate days, then they are probably periods of bay seiching. Two bandwidths were found: 15.7-21.5 min (hereafter referred to as the average, 18.6 min) and 12.8-14.1 min (13.4 min). All the during spectra have oscillations within these two bandwidths. These two periods then are selected as being associated with bay seiching.

Define an amplitude coefficient, A, to be:

$$A = \frac{\text{amplitude at Santa Cruz}}{\text{amplitude at Monterey}}$$

The amplitude coefficients for the 13.4 and 18.6 min oscillations can be easily computed. Multiplying the energy density in a bandwidth by the bandwidth will give a measure of the energy. Taking the square root of this energy gives a relative amplitude for each station. The amplitude coefficients for the 13.4 and 18.6 min oscillations are given in Table VII. The coefficients are in good agreement, and are much less than would be predicted by Wilson's model.

TABLE VII

Amplitude Coefficients for 23 January and 20 April

BANDWIDTH (min)	AMPLITUDE COEFFICIENT 23 January	20 April
15.7-21.5	2.78	1.74
12.8-14.1	2.20	3.80

Thus, the two periods of oscillation selected in this report have similar characteristics and probably represent seiching in the bay. Also, since the amplitudes at Monterey and Santa Cruz are of the same order of magnitude, it appears that oscillations can occur which do not act independently of each other with greatly different amplitudes at each end. This is not to say that the canyon cannot be a nodal line for bay seiching (it is certainly reasonable that oscillations over the canyon are quite small, as predicted in Wilson's model), but it is not reasonable, based on the above results, that the canyon uncouples all seiching in the northern and southern halves of the bay.

V. SUMMARY

The Monterey Submarine Canyon has an effect on the seiching motions in Monterey Bay, but does not appear to divide the bay into two, independent oscillating basins. Some seiching action in the bay on 23 January and 20 April 1969 occurred over the entire length of the bay, having amplitudes of the same order of magnitude at Monterey and Santa Cruz.

APPENDIX A

Use of the Calma Co. Model 480 Digitizer

The Calma Model 480 digitizer located at the Fleet Numerical Weather Central (FNWC) Point Pinos annex was used to digitize the Monterey data. This method of digitizing proved to be both faster and more accurate than template methods.

The digitizer reads and records data in the X and Y directions with a sampling interval which can be set to 0.01, 0.02, 0.04, 0.08, or 0.15 in. The sampling interval used for this study was 0.01 in for both the X and Y directions. The maximum absolute sampling error for the machine is 0.012 in. The output is external BCD, stored on 556 bpi, 7 channel, tape. The tape can be made compatible with the IBM/360 system. It was easier, however, to use the CDC/6500 computer at FNWC.

A simple program, CONVERT, for interpreting the digitized record is presented in Figure 16. This program accomplishes six steps:

1. Converts the data from external BCD to display code.
2. Arranges the data in column matrices of 80 character length.
3. Interrogates each character in the matrix to determine if the character is a
   a. flag.
   b. plus or minus travel in the X-direction.
   c. plus or minus travel in the Y-direction.
4. Sums the Y-direction travel.
5. Prints the Y value, V(m), for each 0.01 in increment travel in the X-direction.
6. Punches cards for the amplitude values which were subsequently used as data input for RHARM on the IBM/360.

Headings may be entered on the tape with the keyboard control, but CONVERT is not designed to read tape headings nor does the program have the capability to search for a particular set of data on the tape. Consequently, all data on the tape will be analyzed each time CONVERT is used. This requires that the user know the sequence of digitized data on the tape.

The digitizing procedure for which CONVERT is designed is listed below. This procedure is followed for each interval digitized.

1. Flag the tape using the "Flag" foot pedal on the machine.
2. Digitize the interval desired.
3. Flag the tape twice.
4. Enter IRG on the tape by pressing the proper key on the keyboard console.

Detailed information on the operation of the digitizer, plus limited computer programming information, can be found in the Model 480 Digitizer Instruction and Maintenance Manual.

FIGURE 16

```
      PROGRAM CONVERT (INPUT,OUTPUT,PUNCH)

      DIMENSION U(5000),V(5000),N(80),NK(80),IBUFF(3000)
      READ 100,L
 100  FORMAT(I2)
      DO 125 JJ=1,L
      READ 101,AVGX
 101  FORMAT(F10.0)
      DELT=36.0/AVGX
C     AVGX IS THE AVERAGE DISTANCE THE RECORDING DRUM OF THE
C     TIDE GAGE ADVANCES PER HOUR.
      PRINT 102,DELT
 102  FORMAT(1H0,2X,25H, SAMPLING INTERVAL EQUALS,1X,E15.7,
     11X,7H SECONDS)
      PRINT 103,JJ
 103  FORMAT(1H0,9H JJ EQUALS,2X,I2)
      DO 104 I=1,5000
      U(I)=0.0
 104  V(I)=0.0
      DO 106 I=1,3000
 106  IBUFF(I)=0
      COUNTX=0.0
      COUNTY=0.0
      NUM=3000
      M=1
      K8=0
      CALL LIOF(5LRBCD1,IBUFF,NUM,NPAR,NEOF)
      IF(NEOF) 602,107
 107  K=-7
      KF=0
 108  K=K+8
      KA=K+8
      KC=0
      DO 109 KB=K,KA
      KC=KC+1
 109  NK(KC)=IBUFF(KB)
      DECODE(80,110,NK)  (N(I),I=1,80)
 110  FORMAT(80R1)
      DO 120 I=1,80
      IF(N(I).EQ.47B) GO TO 111
      IF(N(I).EQ.50B) GO TO 113
      IF(N(I).EQ.55B) GO TO 114
      IF(N(I).EQ.34B) GO TO 115
C     SYMBOL "*",(47B), IS A FLAG.
C     SYMBOL "/", (50B), REPRESENTS AN INCREMENT TRAVEL IN
C    THE MINUS X OR Y DIRECTION.
C     SYMBOL "C", (55B), REPRESENTS ZERO TRAVEL IN THE X OR
C     Y DIRECTION.
C     SYMBOL "1", (34B), REPRESENTS AN INCREMENT TRAVEL IN
C     THE POSITIVE X OR Y DIRECTION.
      GO TO 120
 111  PRINT 112,M,I
 112  FORMAT(1H0,2I10)
      IF(M.GT.10) GO TO 121
      GO TO 120
 113  RX=-0.01
      K8=K8+1
      GO TO 116
 114  RX=0.0
      K8=K8+1
      GO TO 116
 115  RX=0.01
      K8=K8+1
 116  K3=K8/2
      K3=2*K3
      IF(K3.EQ.K8)  GO TO 118
      COUNTX=COUNTX+RX
      IF(COUNTX.NE.0.0) GO TO 117
      GO TO 120
```

```
117   U(M)=COUNTX
      GO TO 120
118   COUNTY=COUNTY+RX
      IF(COUNTX.NE.0.0)  GO TO 119
      GO TO 120
119   V(M)=COUNTY
      COUNTX=0.0
      M=M+1
      IF(M.GT.5000)  GO TO 600
120   CONTINUE
121   TIME=(M*DELT)/3600.
      PRINT 122,TIME
122   FORMAT(1H ,10X,28H TOTAL TIME OF RECORD EQUALS,2X,
      E15.7,2X,7H HOURS.)
      PRINT 123,(V(I),I=1,M)
123   FORMAT(1H ,10X,14F7.2)
      PUNCH 124,(V(I),I=1,M)
124   FORMAT(14F5.2)
125   CONTINUE
      STOP
600   PRINT 601
601   FORMAT(1H1,20X,37H **** U AND V SPACE INADEQUATE ****)
602   STOP
       END
```

APPENDIX B

Raw Spectra

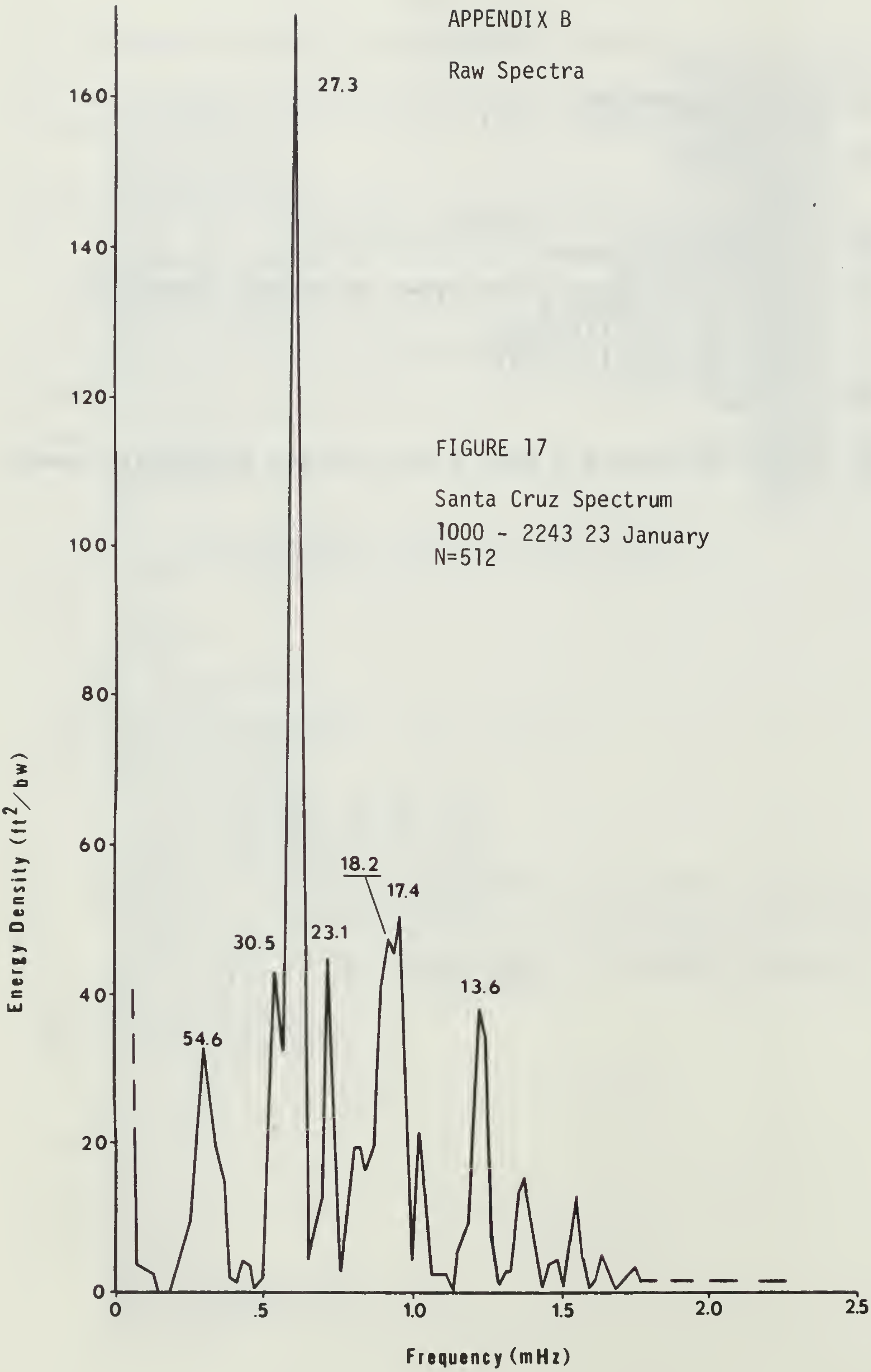


FIGURE 17

Santa Cruz Spectrum

1000 - 2243 23 January

N=512

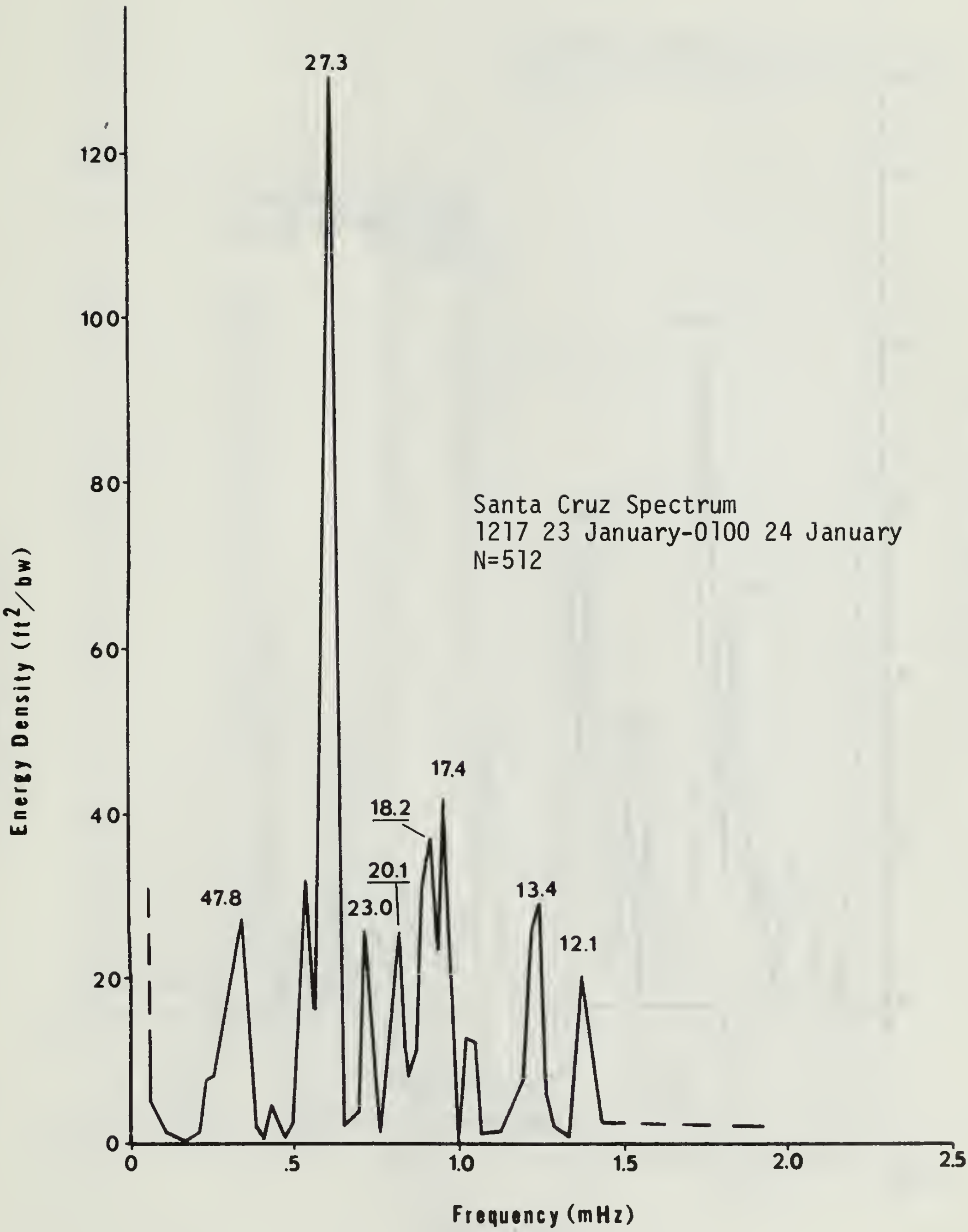

Energy Density (ft²/bw)
Frequency (mHz)
Santa Cruz Spectrum
1217 23 January-0100 24 January
N=512
27.3
17.4
18.2
20.1
23.0
47.8
13.4
12.1
0
20
40
60
80
100
120
.5
1.0
1.5
2.0
2.5

FIGURE 18

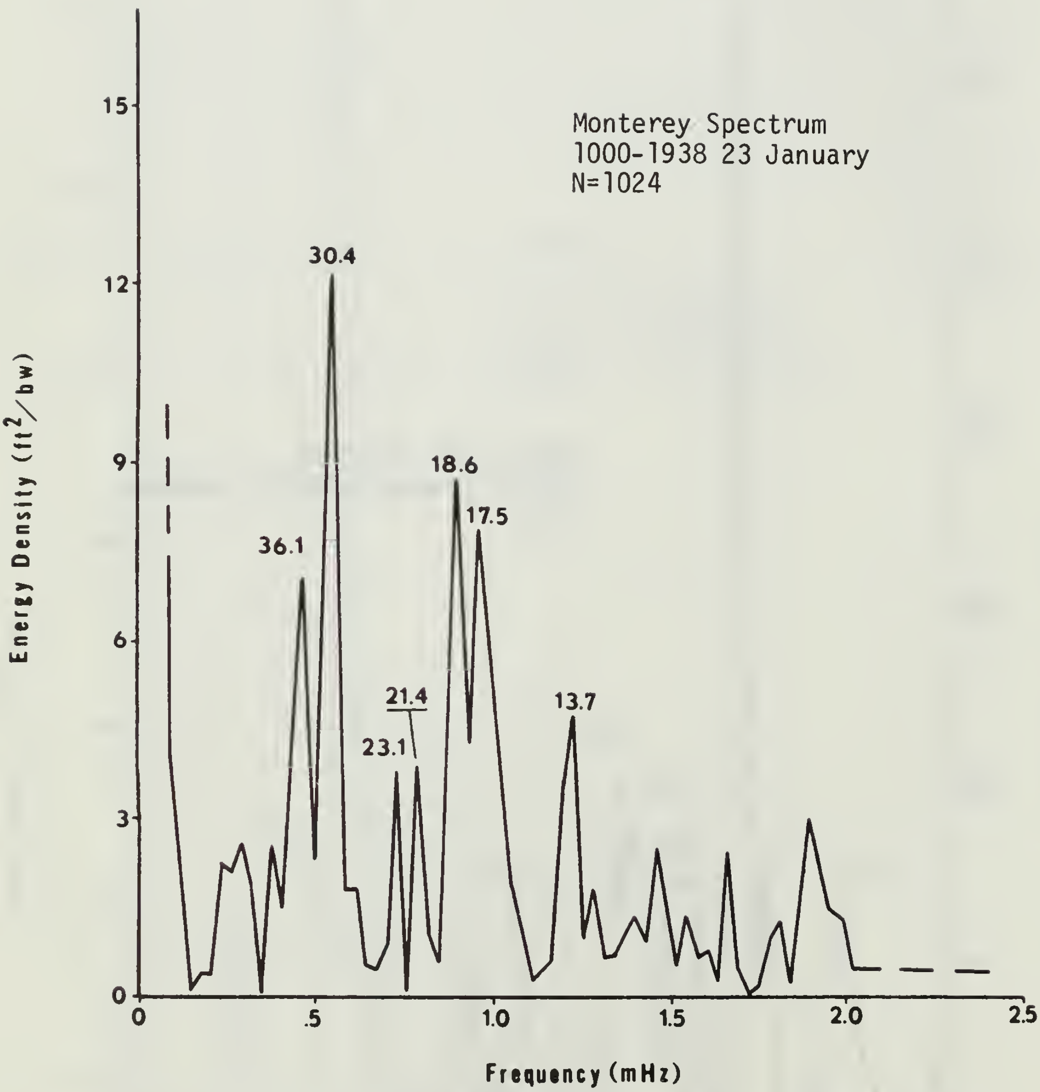

Monterey Spectrum
1000-1938 23 January
N=1024
30.4
36.1
18.6
17.5
21.4
23.1
13.7
Energy Density (ft2/bw)
15
12
9
6
3
0
0
.5
1.0
1.5
2.0
2.5
Frequency (mHz)

FIGURE 19

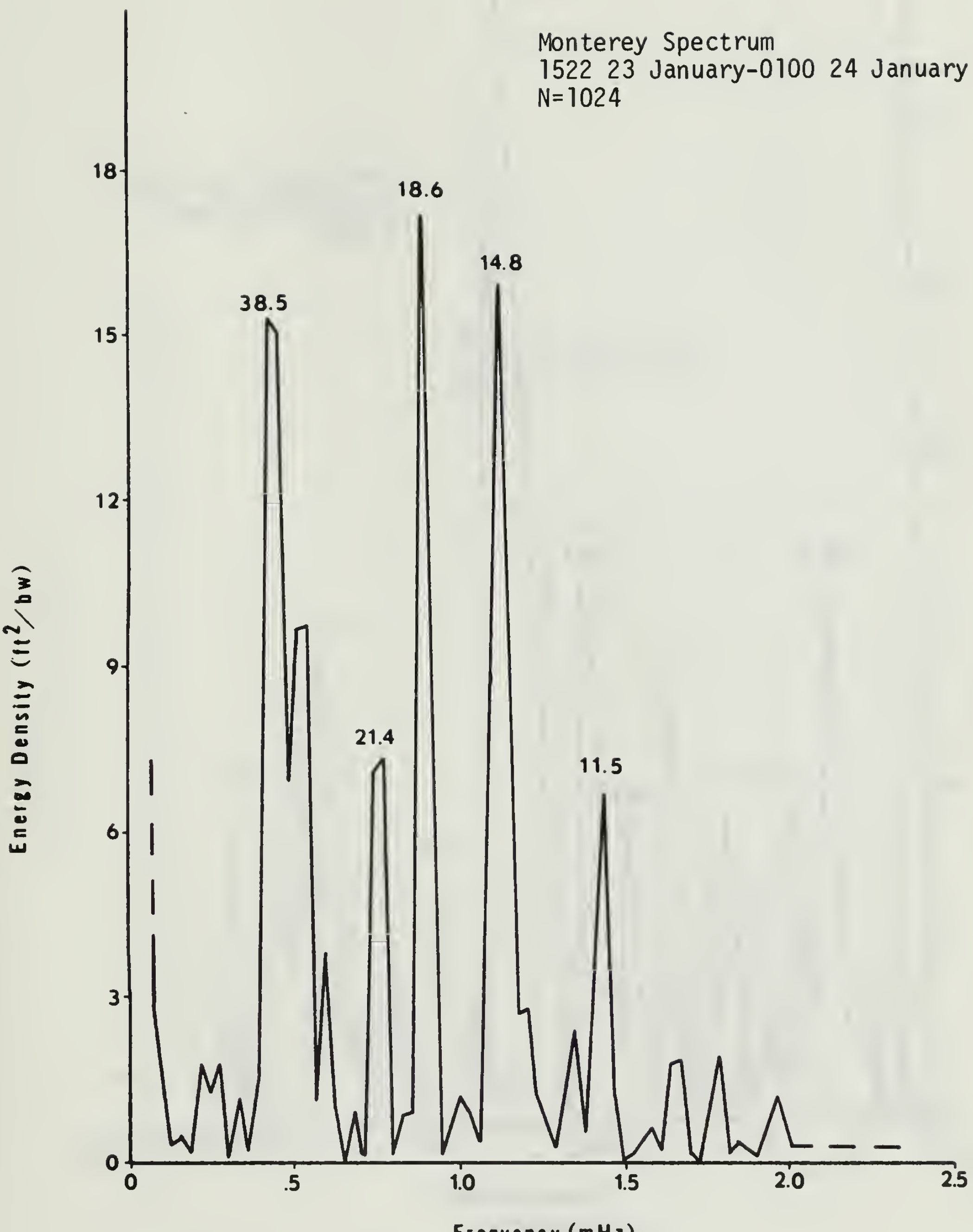

Monterey Spectrum
1522 23 January-0100 24 January
N=1024
38.5
18.6
14.8
21.4
11.5
Energy Density (ft²/bw)
Frequency (mHz)
0
3
6
9
12
15
18
.5
1.0
1.5
2.0
2.5

FIGURE 20

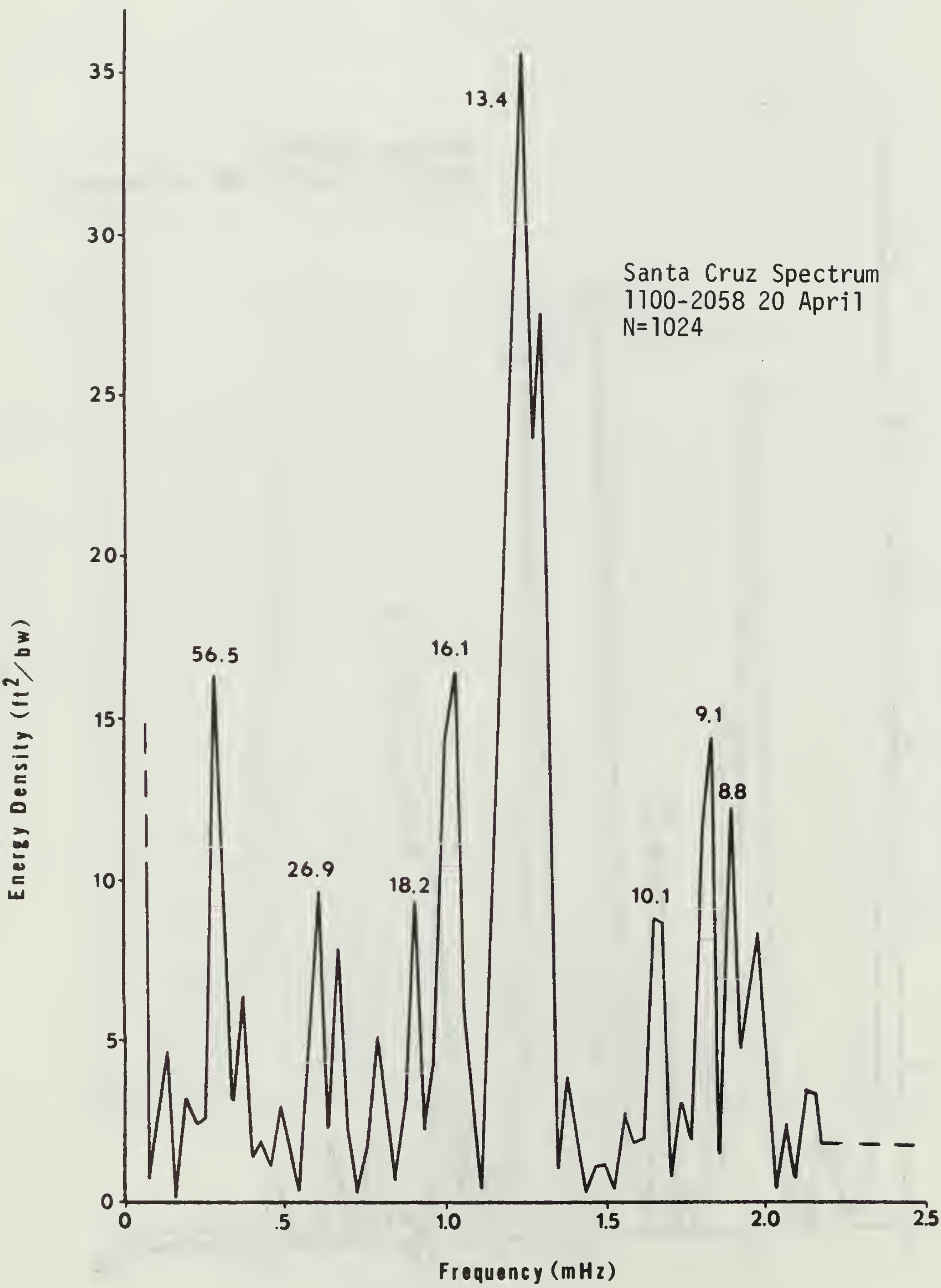

Santa Cruz Spectrum
1100-2058 20 April
N=1024
13.4
56.5
16.1
26.9
18.2
10.1
9.1
8.8
Energy Density (ft²/bw)
Frequency (mHz)
0
5
10
15
20
25
30
35
.5
1.0
1.5
2.0
2.5

FIGURE 21

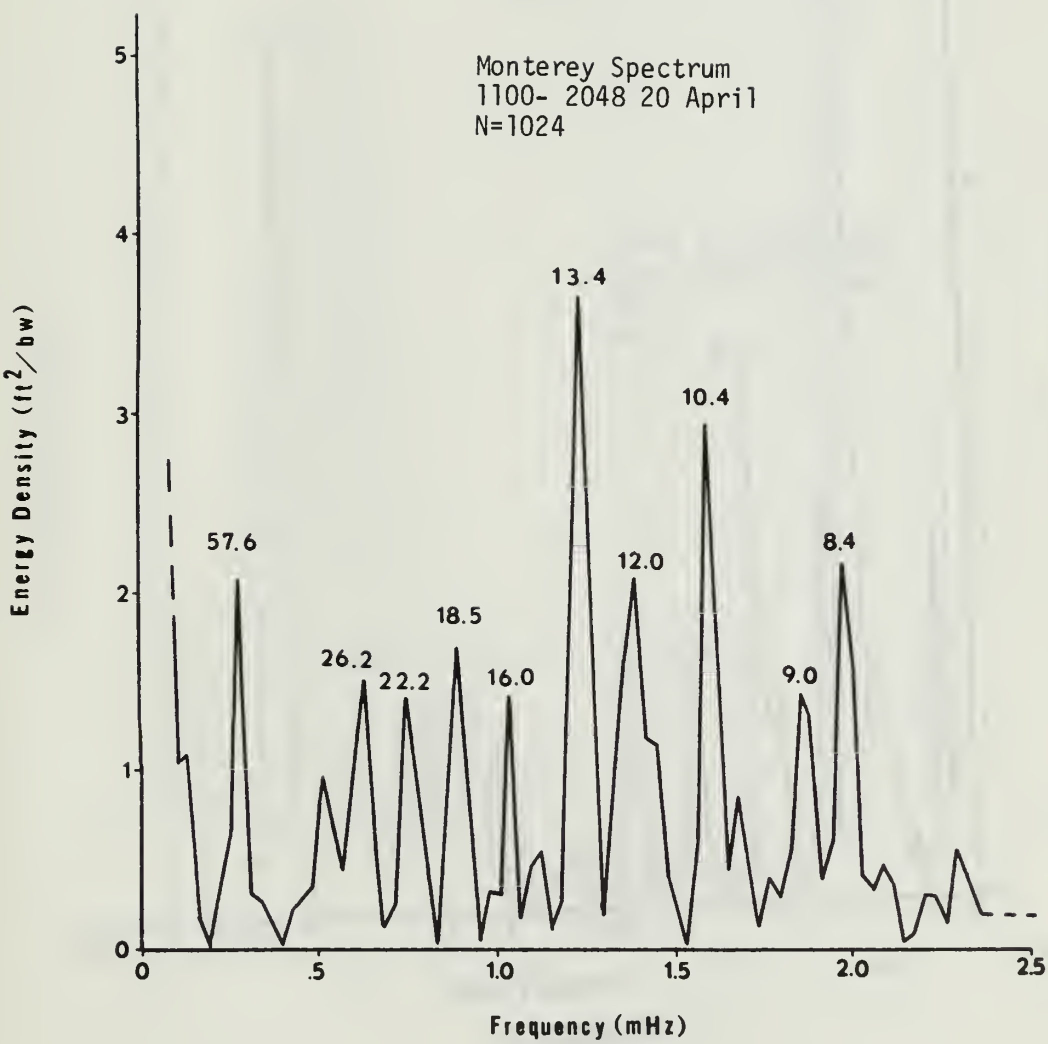

Monterey Spectrum
1100- 2048 20 April
N=1024
Energy Density (ft^2/bw)
Frequency (mHz)
57.6
26.2
22.2
18.5
16.0
13.4
12.0
10.4
9.0
8.4
0
.5
1.0
1.5
2.0
2.5
1
2
3
4
5

FIGURE 22

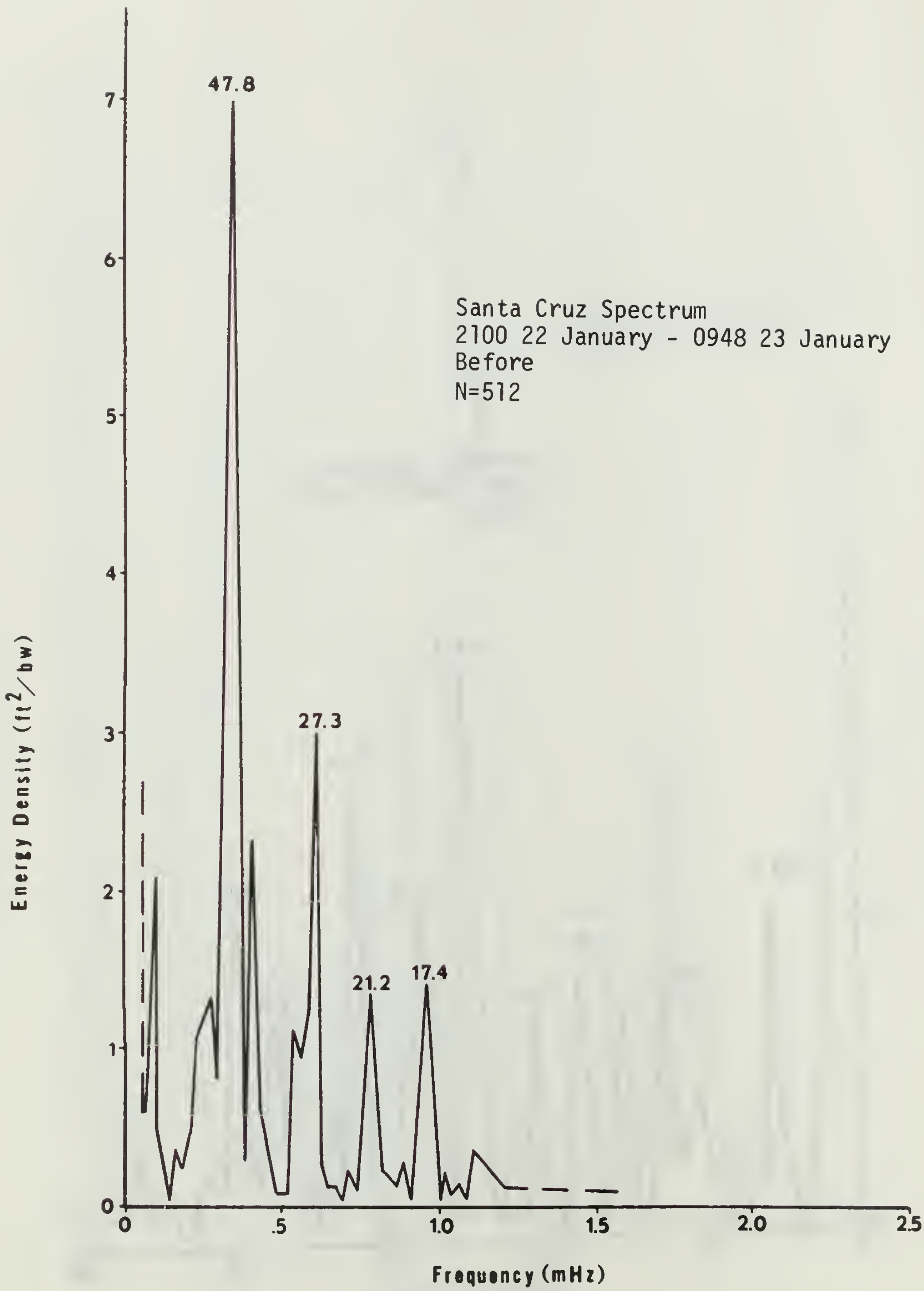

47.8
27.3
21.2
17.4
Santa Cruz Spectrum
2100 22 January - 0948 23 January
Before
N=512
Energy Density (ft²/bw)
Frequency (mHz)
0
1
2
3
4
5
6
7
.5
1.0
1.5
2.0
2.5

FIGURE 23

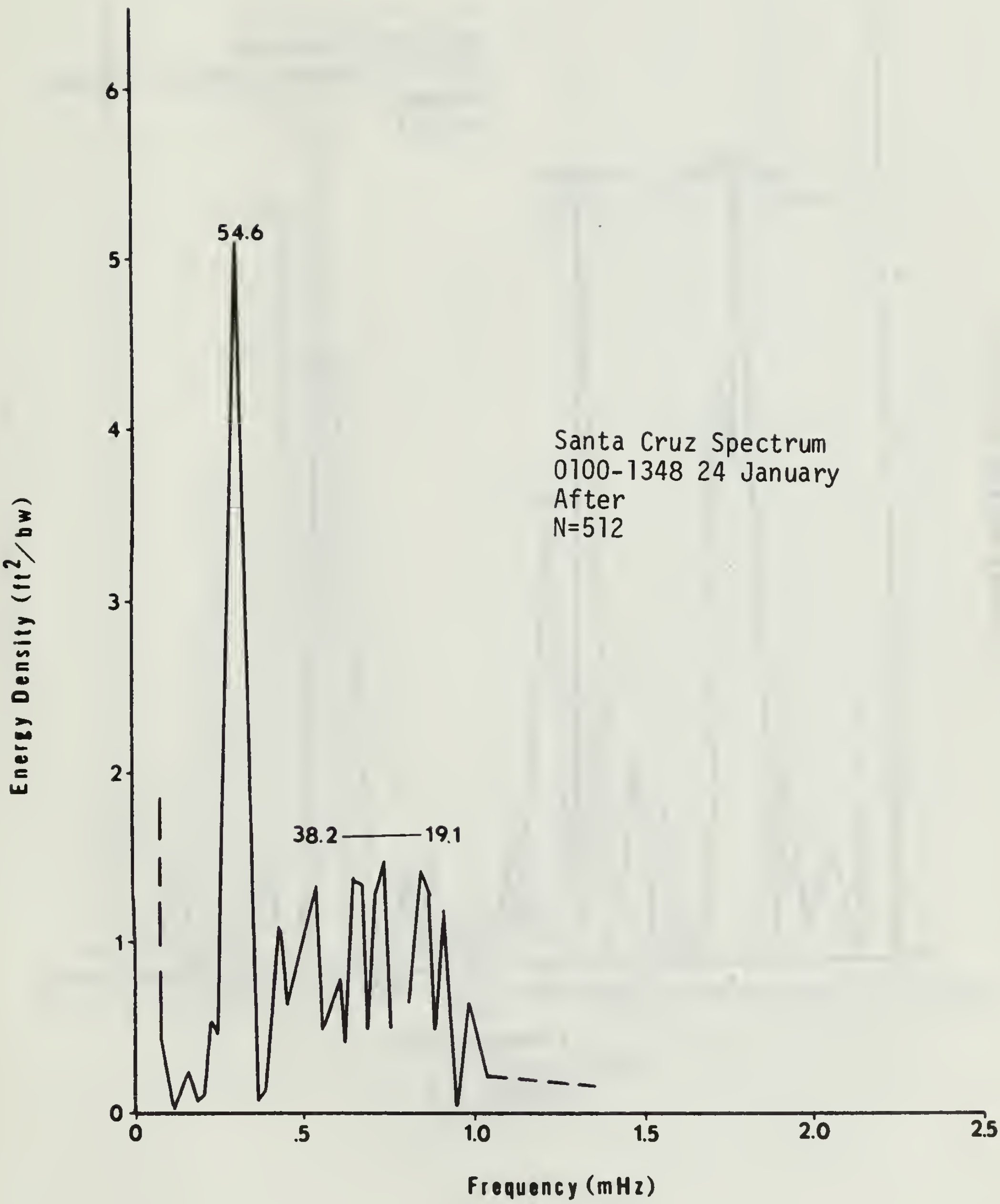

54.6
38.2
19.1
Santa Cruz Spectrum
0100-1348 24 January
After
N=512
Energy Density (ft²/bw)
Frequency (mHz)
0
1
2
3
4
5
6
.5
1.0
1.5
2.0
2.5

FIGURE 24

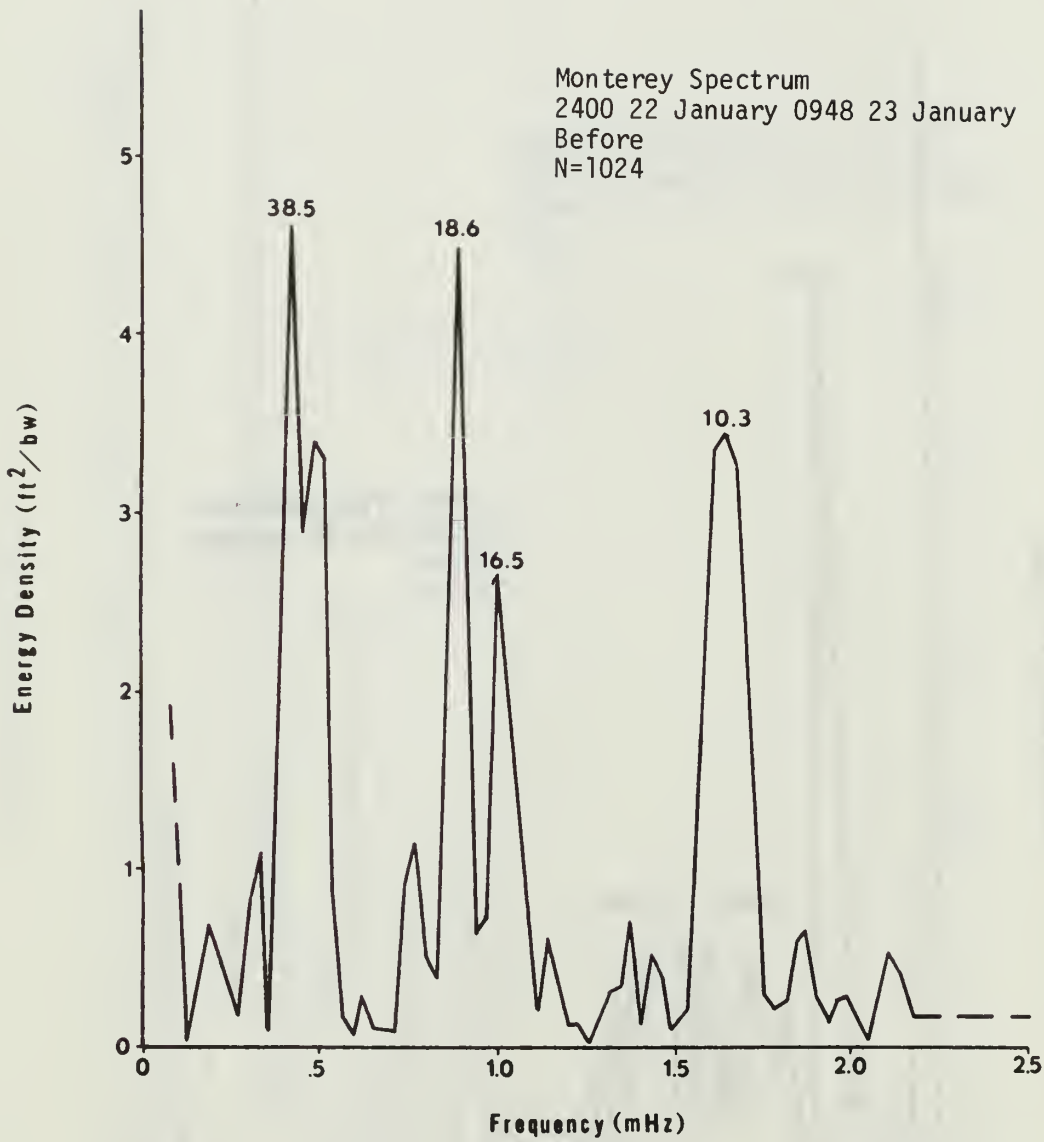
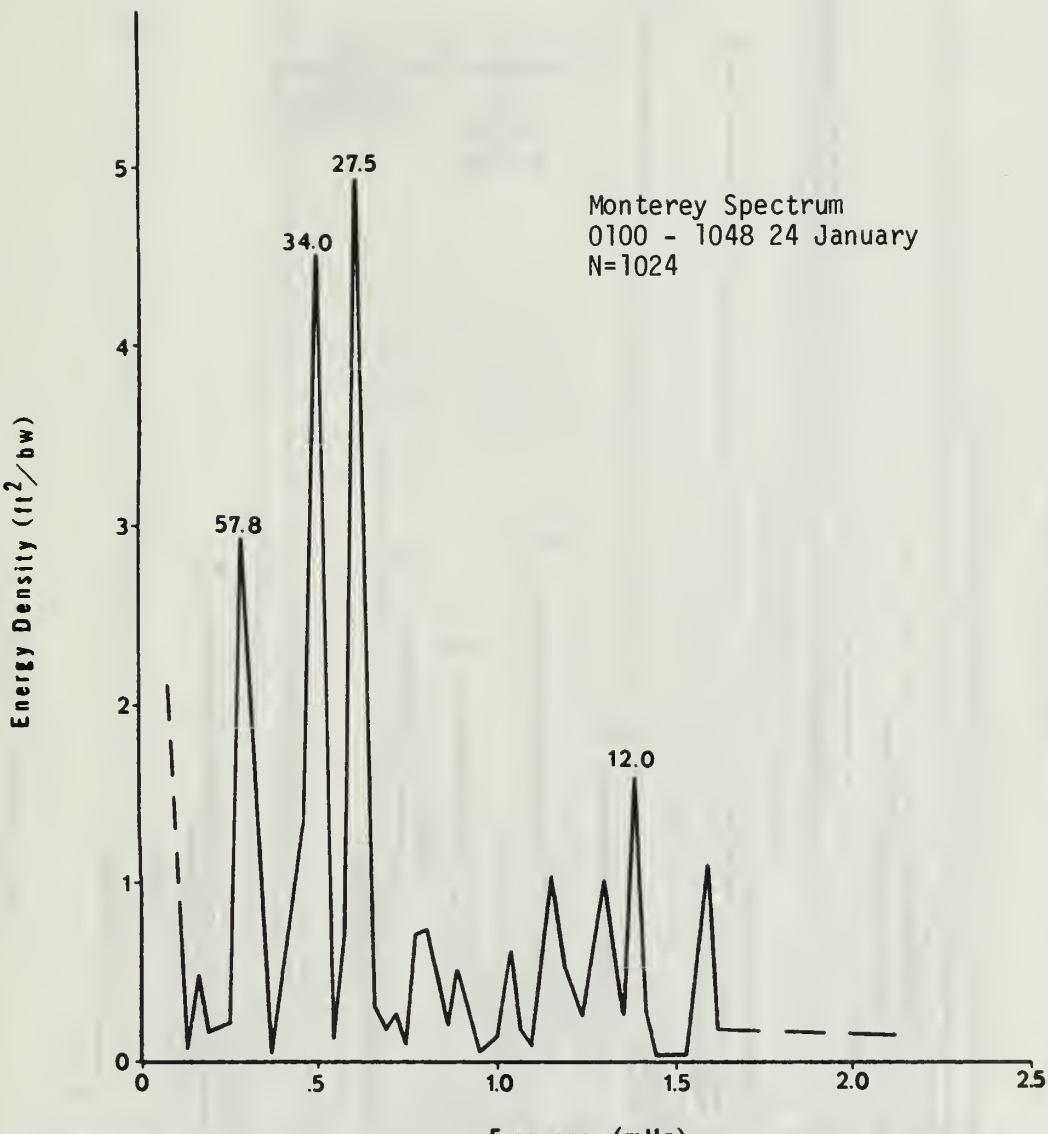
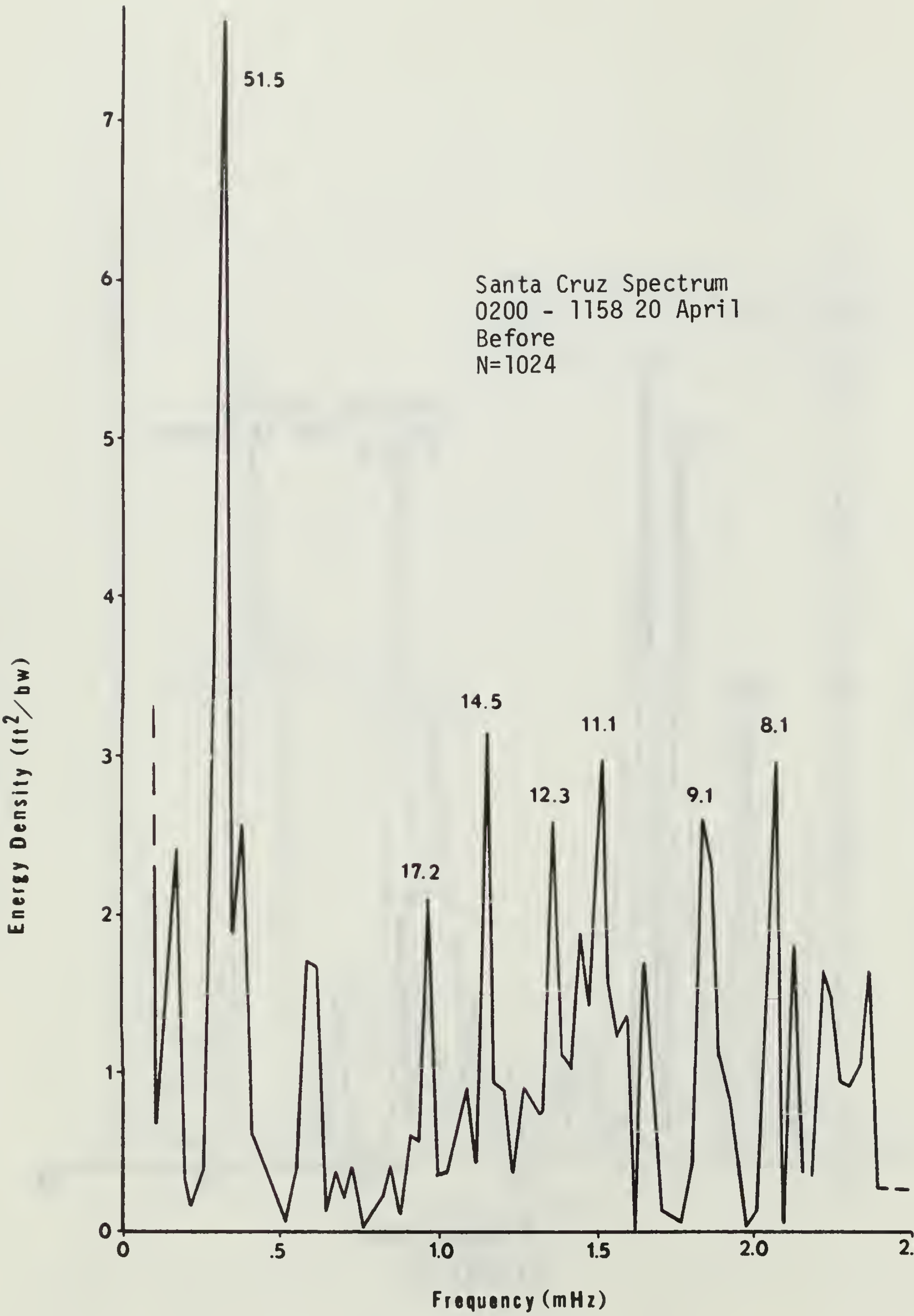

Monterey Spectrum
2400 22 January 0948 23 January
Before
N=1024
38.5
18.6
16.5
10.3
Energy Density (ft²/bw)
Frequency (mHz)
0
1
2
3
4
5
.5
1.0
1.5
2.0
2.5

FIGURE 25



Monterey Spectrum
0100 - 1048 24 January
N=1024
27.5
34.0
57.8
12.0
Energy Density (ft²/bw)
Frequency (mHz)
0
1
2
3
4
5
.5
1.0
1.5
2.0
2.5

FIGURE 26



51.5
Santa Cruz Spectrum
0200 - 1158 20 April
Before
N=1024
14.5
11.1
8.1
12.3
9.1
17.2
Energy Density (ft^2/bw)
0
1
2
3
4
5
6
7
.5
1.0
1.5
2.0
2.5
Frequency (mHz)

FIGURE 27

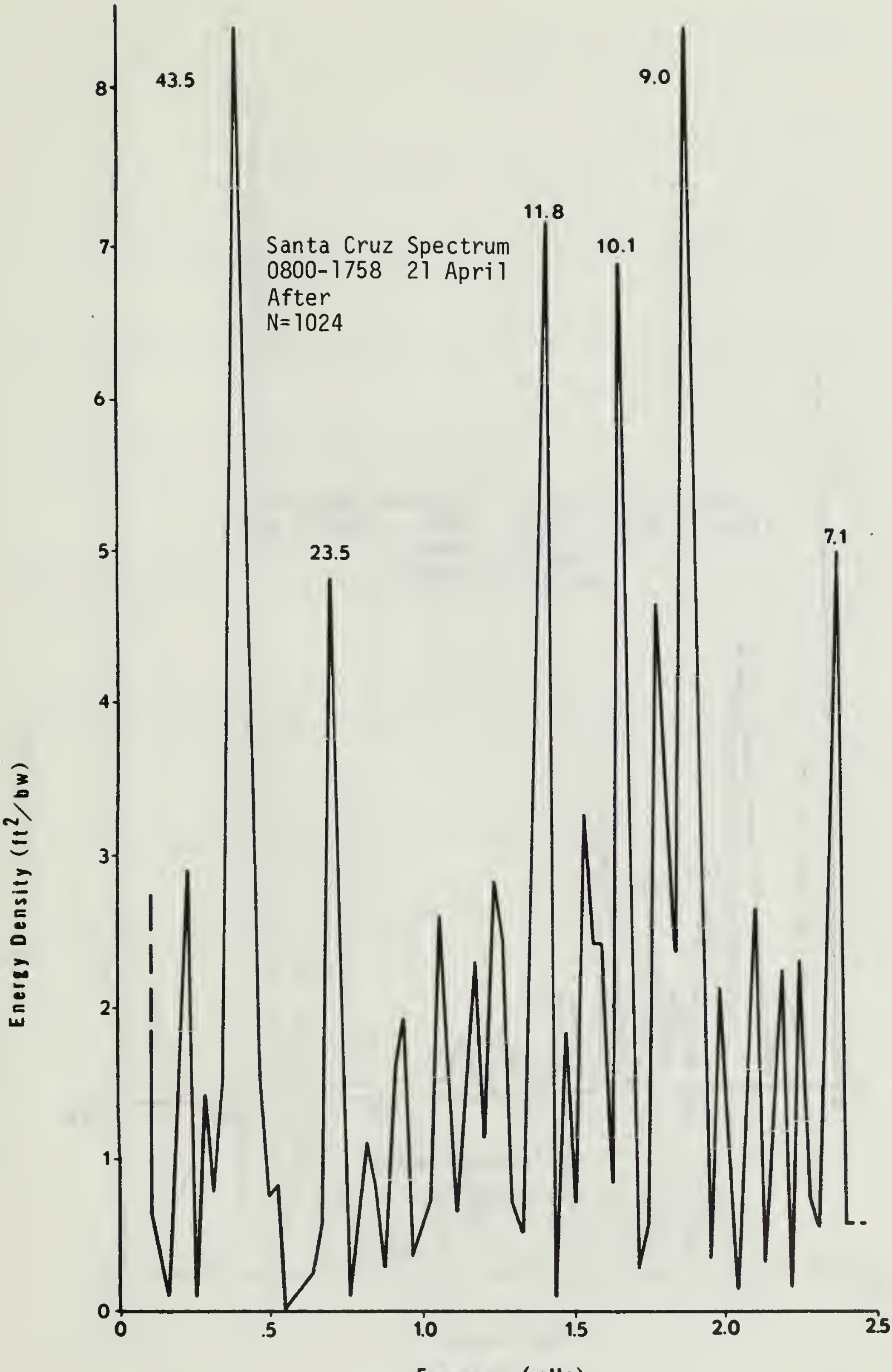

Santa Cruz Spectrum
0800-1758 21 April
After
N=1024
43.5
23.5
11.8
10.1
9.0
7.1
Energy Density (ft²/bw)
Frequency (mHz)
0
1
2
3
4
5
6
7
8
0
.5
1.0
1.5
2.0
2.5

FIGURE 28

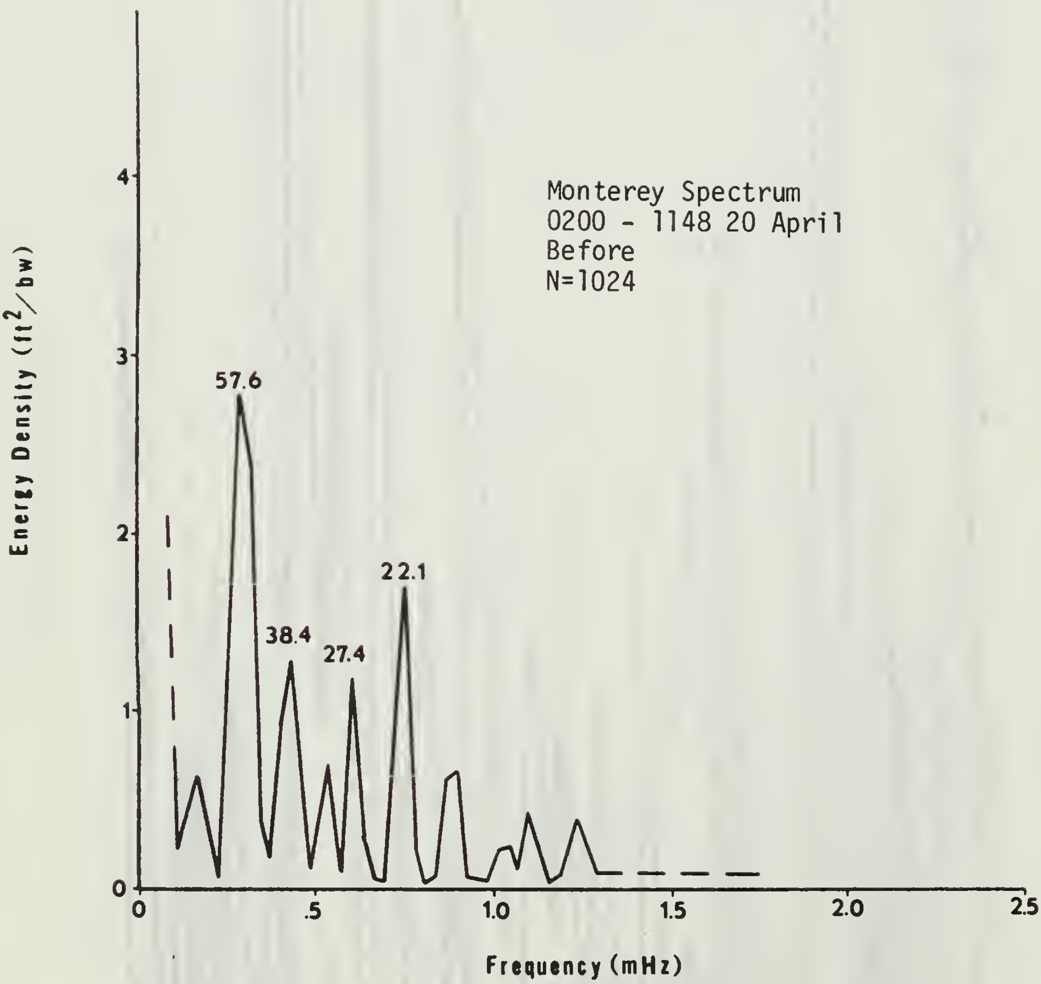

Monterey Spectrum
0200 - 1148 20 April
Before
N=1024
Energy Density (ft²/bw)
57.6
38.4
27.4
22.1
0
1
2
3
4
0
.5
1.0
1.5
2.0
2.5
Frequency (mHz)

FIGURE 29

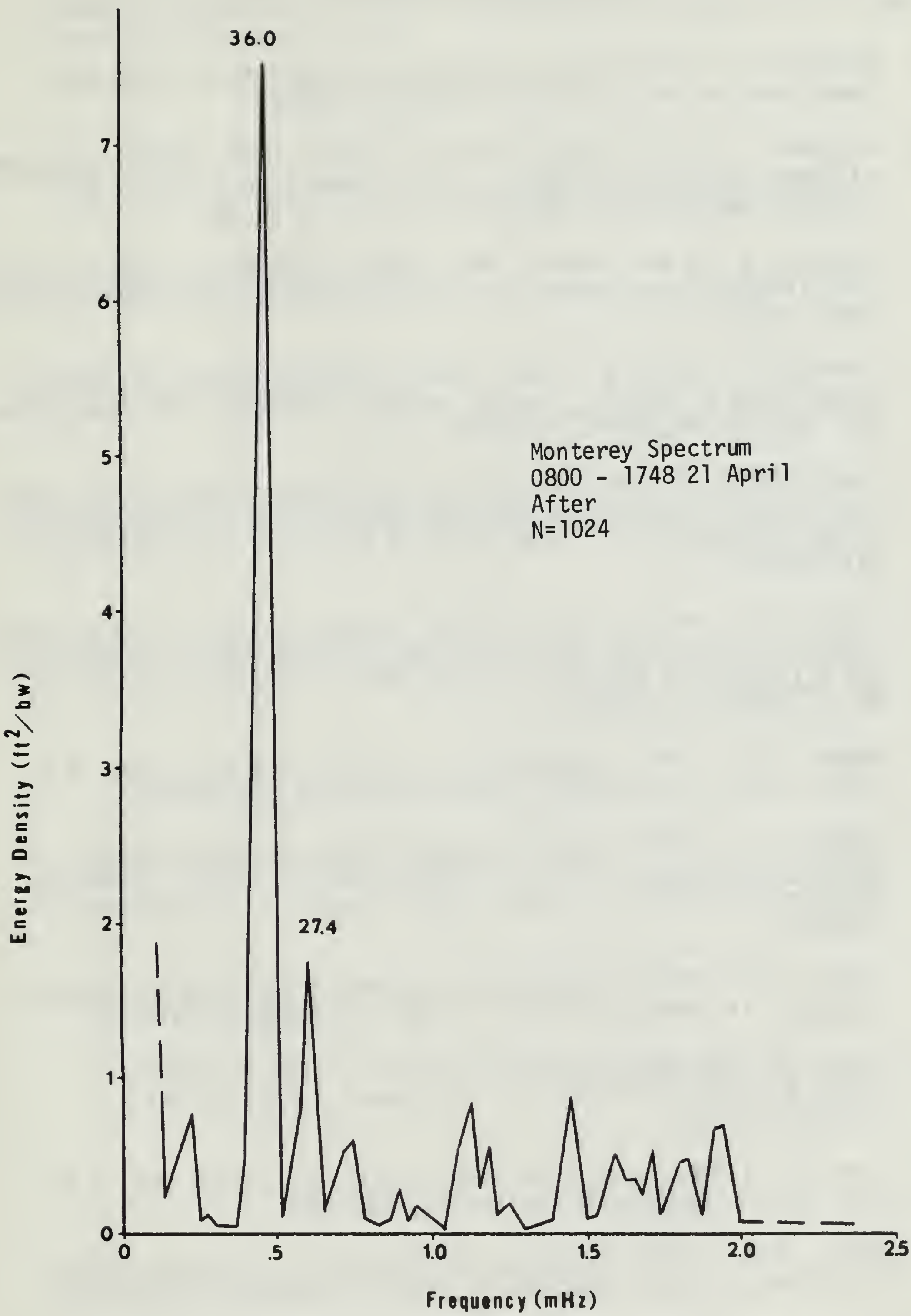

36.0
27.4
Monterey Spectrum
0800 - 1748 21 April
After
N=1024
Energy Density (ft²/bw)
7
6
5
4
3
2
1
0
0
.5
1.0
1.5
2.0
2.5
Frequency (mHz)

FIGURE 30

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13. ABSTRACT

The effect of the Monterey Submarine Canyon on seiching in Monterey Bay is not well known. Spectral analyses of simultaneous tidal records from the north-south extremities of the bay were performed for 23 January and 20 April 1969 to investigate this effect. Both day's records had long-wave activity of which seiching was at least a contributing mechanism. Analyses of the computed spectra for the periods during the long-wave activity, and ten-hour periods both before and after, indicate that the seiching motion in Monterey Bay has similar amplitudes at the north-south extremities.

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Monterey Bay						
Spectral Analysis						