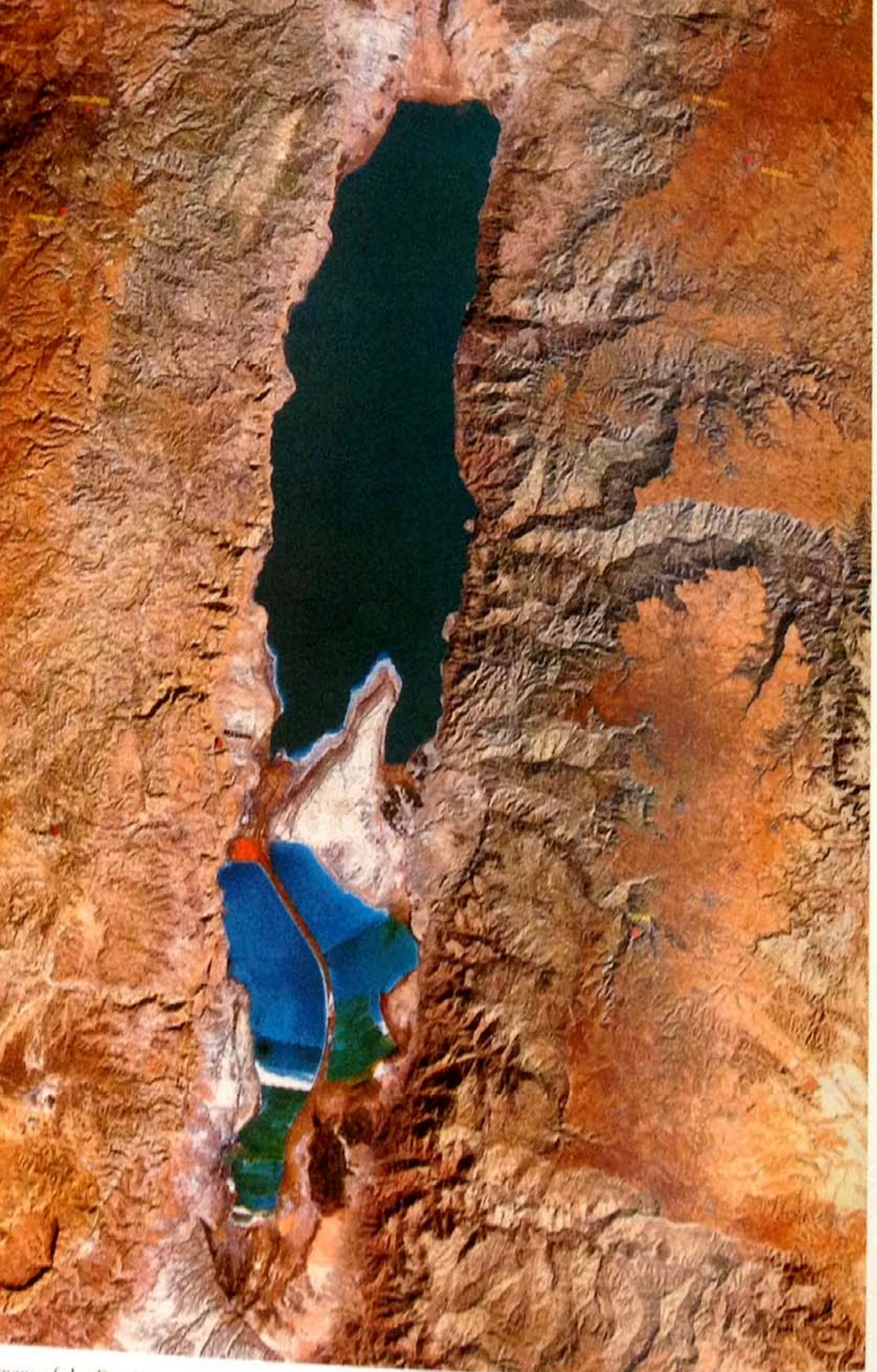

nage of the Dead Sea produced by merging sequential LANDSAT 5 thematic mapper color scenes
ary 18, 1987 with 10 m panchromatic imagery of Israel from the French SPOT satellite (© C.N.E.S.,
Productions Ltd., Educational Programs, Inc., 1990).

THE DEAD SEA

The Lake and Its Setting

Edited by

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10. WIND WAVES ON THE DEAD SEA

Artur Hecht, Tal Ezer, Avraham Huss, and Aviv Shapira

There is very little documented information on wind waves on the Dead Sea. The information we have was contributed by Neev and Emery (1967), who based their report solely on visual observations. In general, they report a diurnal cycle during which the sea is calm and mirror-like until about 1000 hours. This is followed by a gradual intensification of the wave field, which reaches its peak at about 1500 hours and then dies out to become calm again at about 2000 hours. According to their report, northerly storms in the autumn, winter, and spring produced higher waves, which reached a maximum height of 1.1 m, a length of 10 m, and a period of a few seconds. They compare the wave field on the Dead Sea to that on Lake Kinneret, where, for similar winds but much shorter fetches, waves of 2 or even 3 m high were reported. Neev and Emery (1967) attribute this paradox to the higher density of the Dead Sea.

Direct wave measurements on the Dead Sea were taken, for the first time from October 1982 to January 1983. These measurements were taken by the Israel Oceanographic and Limnological Research Ltd. (IOLR) and are the subject of the present investigation. Subsequent wave, wind and current data are presented in Sirkes et al. (chapter 9, this volume).

DATA ACQUISITION AND ANALYSIS

Wave heights were measured with an Environmental Devices Corporation (ENDECO) buoy deployed in 45 m of water, about 3.5 km east of the mouth of the Mishmar River (Fig. 10-1). The buoy measured vertical accelerations induced by the waves, integrated the measurements twice, and transmitted the resulting wave heights ashore, where they were recorded. The buoy did not measure wave directions. The accuracy and characteristics of the ENDECO wave-measuring buoy are described in Middleton et al. (1976) and Brainard (1980). The resolution and accuracy of the measurements were ±6 cm. The buoy did not respond significantly to waves of less than 10 cm in height; therefore, our definition of calm seas included waves of up to 10 cm high. The response of the buoy to waves with periods of 3.3 to 14.3 s did not affect the measurement of the wave height. For waves with periods of less than 3.3 s, wave amplitudes were attenuated. The attenuation was as much as 7 dB (that is, 50%) for 1.5-second waves, and as much as 12 dB (that is, 75%) for 1-second waves. The attenuation was corrected according to tables provided by the manufacturer. However, our estimates indicate that the contribution of waves shorter than 2 s was insignificant. The buoy response also attenuates the amplitudes of waves with periods larger than 14 s. However, this is irrelevant because, as we will show, such waves could not possibly develop on the Dead Sea.

We carried out two series of wave measurements. During the first series, October 19, 1982, to January 4, 1983, the analog data from the ENDECO buoy were recorded for 5 minutes every 4 hours. From February 1983 to November 1983, the data from the same buoy were recorded digitally for 10 minutes every hour. The length of the record and the intervals between records were a compromise determined by the minimum length and time interval required for a reasonable analysis versus the capability of the available recording instrument (the analog paper recorder being far more limited than the digital magnetic tape).

As far as the analog data are concerned, the diurnal distribution of the measurements, the length of each record, and the length of the entire series are not suitable for sophisticated mathematical analysis and for a full description of the wave climate in the Dead Sea. Moreover, there are gaps in the recordings resulting from power failures on shore at the recording station. Far more data were collected during the series of digital measurements; however, we were still plagued by power failures and transmission errors. Unfortunately, some of the power failures occurred during storms, when wave development was particularly interesting.

Some of the transmission errors resulted in wave records that were obviously impossible, such as wave heights larger than 10 m. It was easy to weed out and ignore such erroneous records. However, some marginal occurrences were more difficult to decide on. For instance, although everyone would agree that a 10-m wave could not develop on the Dead Sea, what about a 4-m wave? We felt it was necessary to formulate a criterion to eliminate records showing waves that were not obviously wrong but were practically impossible. We decided to base this criterion on the wind climatology of the Dead Sea and the wave prediction method of the Coastal Engineering Research Center Shore Protection Manual, CERC-SPM (Coastal Engineering Research Center, 1984).

According to Figure 20 in Neev and Emery (1967), the strongest winds, 5.5 m/s, were observed during the evening hours of June, July, and August, whereas toward the end of the year and the beginning of winter, the wind maxima diminished to about 2.5 m/s. These results were based on winds measured inland at the northern and southern ends of the Dead Sea, which may be affected by local topography and may not be representative of the wind field at sea. The only wind measurements concurrent with wave measurements were acquired on shore at En Gedi. However, these measurements, in addition to being ashore, were sporadic and sometimes inaccurate. These measurements indicated maximum wind speeds of at most 8 m/s.

Between January 1984 and November 1988, the IOLR measured meteorological parameters at sea. These measurements were acquired by Aanderaa transducers, from a buoy located about 3.5 km east of En Gedi (Fig. 10-1). The meteorological data were averaged over 30-minute intervals and organized into a continuous time series. Technical difficulties caused many interruptions in the continuity of these measurements and, at present, not all the data are available. However, in spite of its limitations, this is the longest and the most detailed set of "at sea" meteorological measurements presently available. Some of the data were interpreted and reported by Weiss et al. (1987), as well as Weiss and Cohen (1988). In the present investigation, we will use some of this meteorological data (i.e., the winds at two levels, at 3.5 m and 6 m about the sea surface, air temperatures, and sea surface temperatures) for climatological information relevant to the analysis of the waves measured on

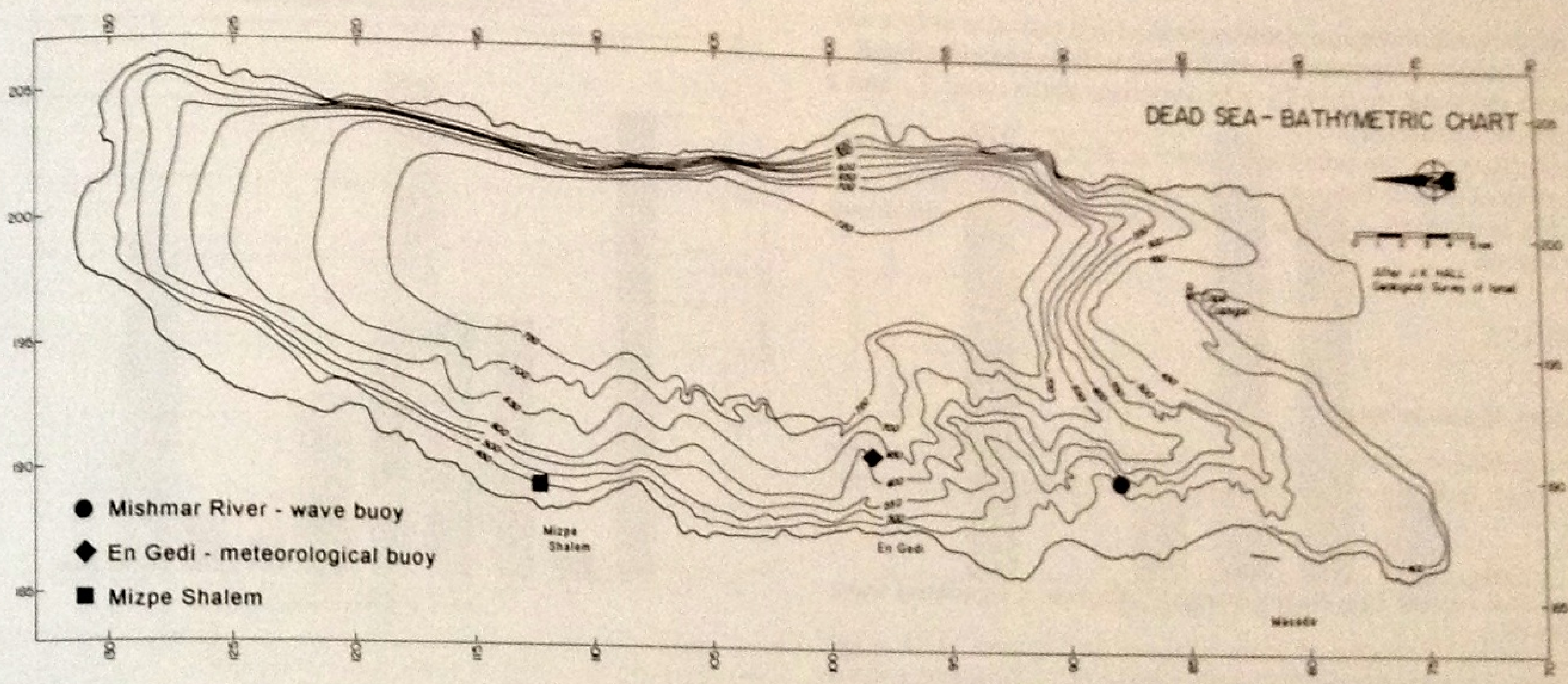

Figure 10-1 Location of the wave buoy off the Mishmar River bed and the meteorological station off En Gedi.

the Dead Sea. The information on the mast height enabled us to compute wind factors compensated for a standard height. The simultaneous air and sea temperature measurements enabled us to compute the air instability factor as required for the wave prediction nomogram of the CERC-SPM (Coastal Engineering Research Center, 1984).

These meteorological data show that, occasionally, the winds reached velocities of 16 m/s at the lower wind gauge and 17 m/s at the higher one. These particular peaks were westerly winds associated with depressions that crossed Israel in the winter and early spring. However, any analysis of the relation between the wave pattern and the coincident weather pattern has to take into consideration that the buoy was located closer to the western and southern shores of the Dead Sea than to its northern and eastern shores (Fig. 10-1). Therefore, with respect to the buoy, winds from the northern quarter (i.e., 0° ±30°) have the largest fetches (about 35 km) and could produce far larger waves than winds of equal speeds from other directions. Thus, intensive western winds do not produce high waves, at least not at the site of the buoy. Very strong northerly winds occurred as well during the winter and early spring. These winds were of the order of 11 m/s (once, even as high as 12.2 m/s). At the time, the air to sea temperature difference was about - 2°C. From the Coastal Engineering Research Center (1984), we find that given these winds, a fetch of 35 km, and a duration of 4 hours, the significant waves and the significant periods are expected to be 1.7 m and 5.5 s (a significant length of 47 m), respectively.

We must stress that the correction factors and the nomogram in the manual are intended for the open ocean, which is certainly not the case in the Dead Sea. Moreover, the empirical evaluations of the manual do not take into consideration such local factors as the particularly high density of the Dead Sea and the vertical component of the winds that result from the geographical position of this sea (i.e., 400 m below sea level with some very steep orographic features surrounding it). At present, we cannot estimate the magnitude of these factors, but we expect that the vertical component of the winds would enhance the wave field. Therefore, we decided to reject a record (the entire record) that showed significant waves heights larger than 3 m. Obviously, to some degree, this is an arbitrary decision.

Subject to this criterion, out of a total of 251 analog records, 12 had to be rejected. Out of a total of 2,058 digital records, 45 had to be rejected. Of the rejected records, only five indicated significant wave heights between 3 and 4 m, and another six indicated significant wave heights between 5 and 6 m. The rest of the rejected records showed wave height that exceeded 10 m and thus were certainly wrong. Moreover, because we managed to acquire only some sporadic measurements since mid-May 1983, we limited our investigation to the data obtained from February to May 1983, that is a total of 1,890 digital records.

Data were analyzed according to Tucker (1963; see also Draper, 1966, 1976). The following parameters were determined for every record: t, the exact duration of the record in seconds; N_C the number of crests; N_Z, the number of upward zero crossings; H_1, the sum of the highest crest and the lowest trough; H_2, the sum of the second highest crest and the second lowest trough; and $T_Z = N_Z/t$, the mean zero crossing period; and $T_C = N_C/t$, the mean crest period. If we assume that the Dead Sea wave heights, like open sea wave heights, are Rayleigh distributed, the measured parameters can provide us with some of the statistical characteristics of the wave field (Longuet-Higgins, 1952) and, in particular, permit the computation of the significant wave height, H_S (or $H_{1/3}$ as it is named sometimes), for each of the wave records. The significant wave height and the significant wave period are defined as "the average height and period of the one-third highest waves" (Tucker, 1963, p. 306).

Another computed parameter is the spectral width, $\varepsilon^2 = 1 - (N_Z/N_C)^2$. This is a measure of the range of frequencies present relative to the mean wave frequency, and it controls the shape of the probability distribution of the heights of the wave crests (Tucker, 1963). Draper (1963, p. 300) describes the significance of this parameter as follows:

> If the wave components cover a wide range of frequencies, the long waves will carry short waves on top of them and there will be many more crests than zero crossings, so that T_C will be much smaller than T_Z and ε will be nearly one. If, on the

other hand, there is a simple swell which contains only a narrow range of frequencies, each crest will be associated with a zero crossing, so that T_C will approximately equal T_Z and ε will be nearly zero.

Finally, since the wind measured at En Gedi coincided only sporadically with the wave measurements, there were no data for the computation of the correlation between the winds and the waves.

RESULTS

Analog Measurements

The significant wave heights, H_S, are given in Table 10-1, where the gaps indicate missing data and 0 indicates calm seas,

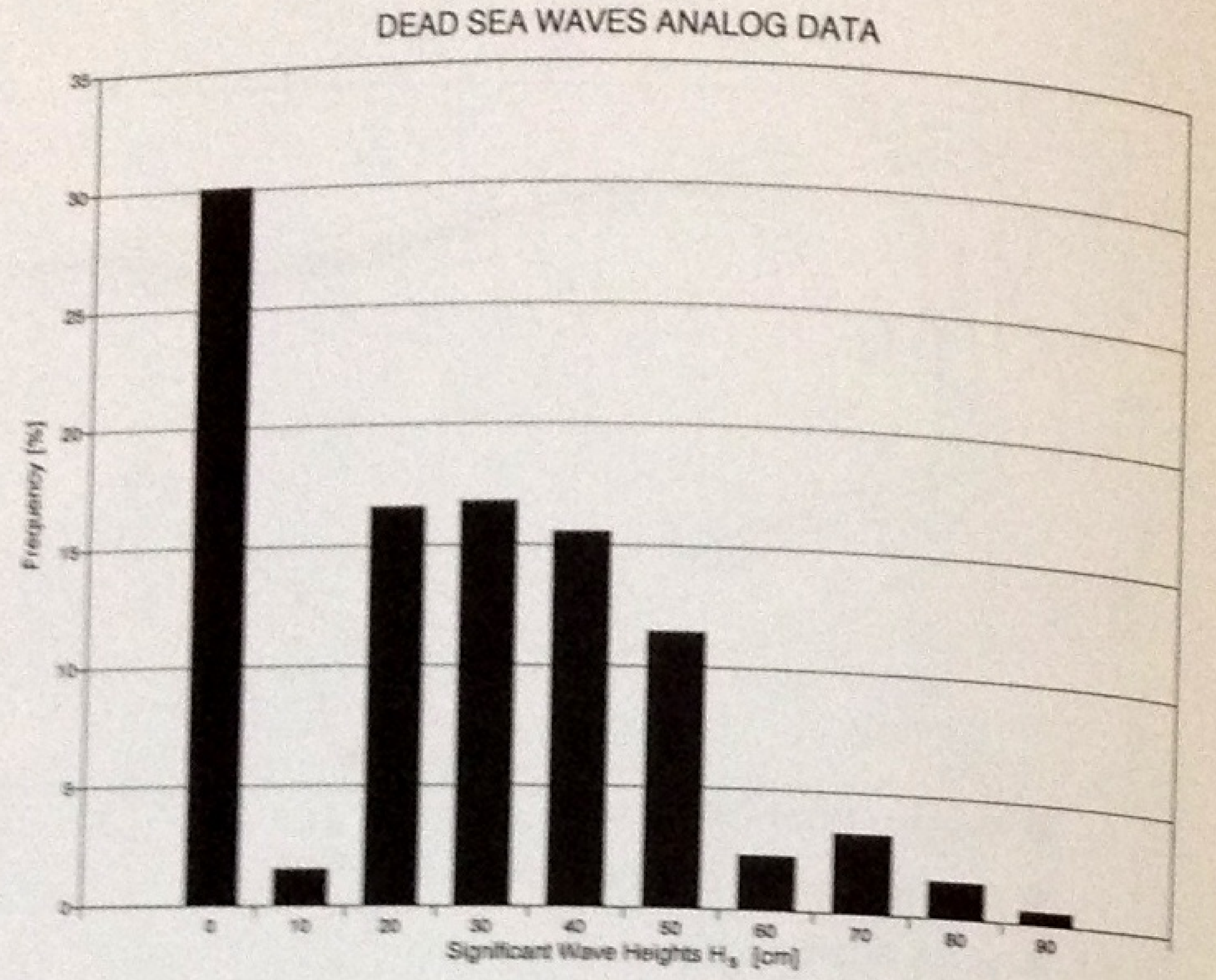

Figure 10-2 Analog data measurements; histogram of significant wave heights (H_S)

Table 10-1 Dead Sea wave measurements: Analog Data (significant wave heights in cm)

	October 1982 Time (Hours)						November 1982 Time (Hours)					
Day	00	04	08	12	16	20	00	04	08	12	16	20
01								34	44	40	21	
02										27		33
03							67	55	46	22	00	00
04							41	35	50	29	00	00
05							50	40		16	00	00
06							10	14	13	00	00	00
07							00	41	44	62	28	
08							00	42	22	18	23	00
09							33	25	00	80	45	30
10							23	24	18	26	18	23
11							00	11	00	00	00	00
12							00	00	11	18	00	00
13							24	41	42	37	15	21
14							40	36	38	23	25	33
15							38	35	43	15	00	31
16							36	68	67	86		
17								29	33	20	00	00
18							13	16	16	12	00	00
19				00	00	34	00	00	00	00	00	00
20	32	16	00	00	00	20	00	00	12	00	23	19
21	28	18	17	00	27	39	00	00	19	00	00	13
22	43	31	42	40	00	00	31	60	60	29	00	17
23	25	25	22	41	41		24	00	11	14	14	28
24				00	00	00	34	23	00	47	00	00
25	37	43	20	00	00	32	20	30	42	37	22	00
26	35	43	28	33	00	29	00	11	00	00	00	14
27	37	14	25	20	00	00	11	19	32	19	00	27
28	39	40	52	24	00	00	23	50	71	34	12	20
29	76	87	75	31			62	66				
30		29	27			00						
31	24	11				00						

	December 1982 Time (Hours)						January 1983 Time (Hours)					
Day	00	04	08	12	16	20	00	04	08	12	16	20
01							20	28	41			34
02							34	32	32	26	00	00
03							13	15	28	16	00	00
04							00	16	30	31		
05												
06					30	00						
07	00	19	00	28	11							
08	00	09	23	00	00	00						
09	00	30	40	33	21	22						
10	41	46	52	38	34	37						
11	61	52	64	34	47	25						
12	20	47	43	41	16	00						
13	22	15	15	16		18						
14	13	00	28	15		00						
15	00	00	16	18	00	00						
16	30	60	48	41	32	24						
17	32	38	19	41	49	45						
18	66	61	47	39	37	25						
19	24	41	40	27	09	00						
20	00	00	00	09	00	00						
21	00	00	24	33	18	00						
22	12	24	40	58	44	39						
23	13	33	53	61	73	49						
24	31	36	71	38	40	44						
25	38	38	45	36	09	00						
26	00	09	15	00	00	00						
27	00	00	00	00	00	21						
28	17	58	43	48	19	19						
29	29	10	00	18	00	16						
30	00	00	17	00	00	00						
31	00	23	33	43	22	13						

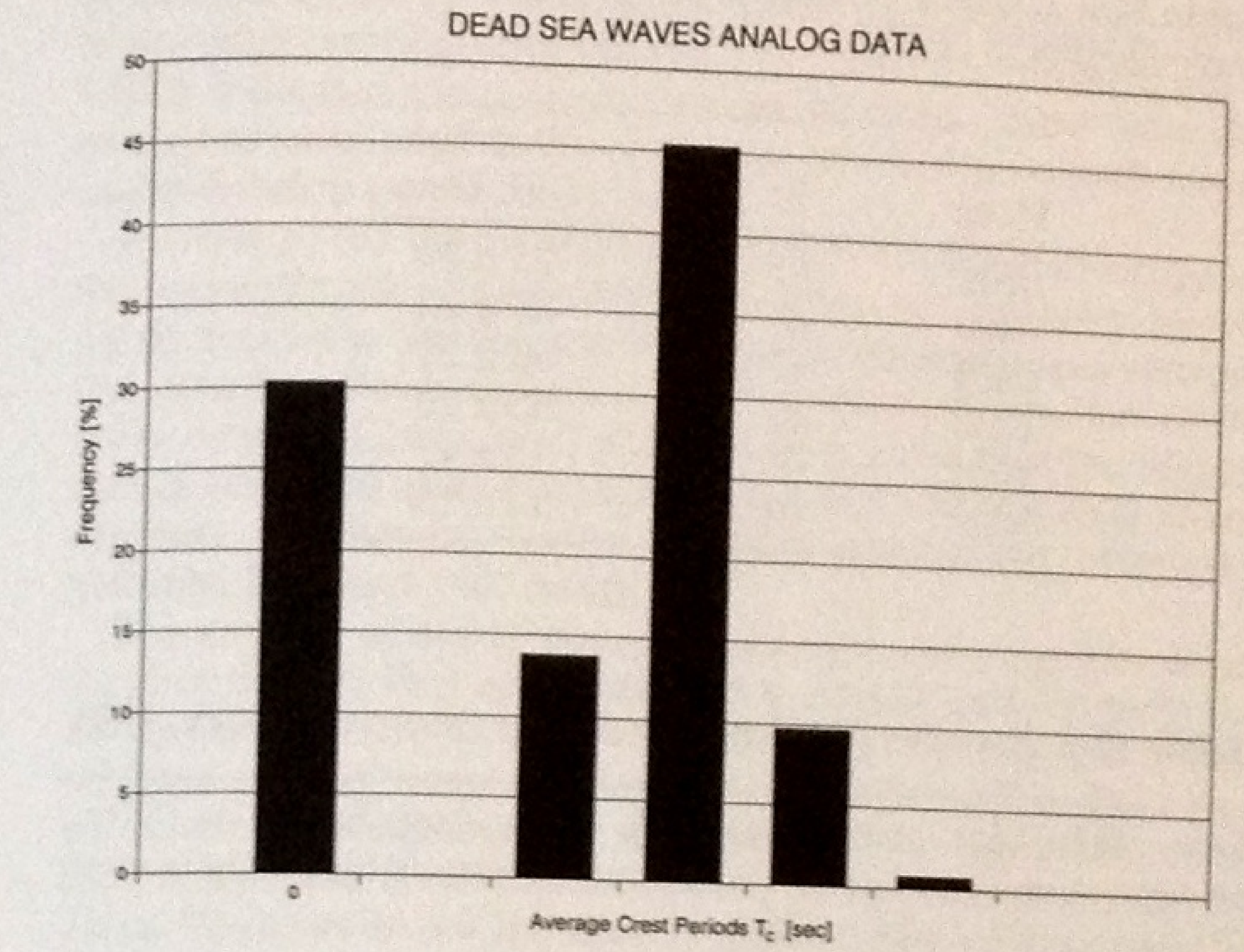

Figure 10-3 Analog data measurements; histogram of average crest periods (T_C). To complete the histogram to 100%, the value for calm seas was included.

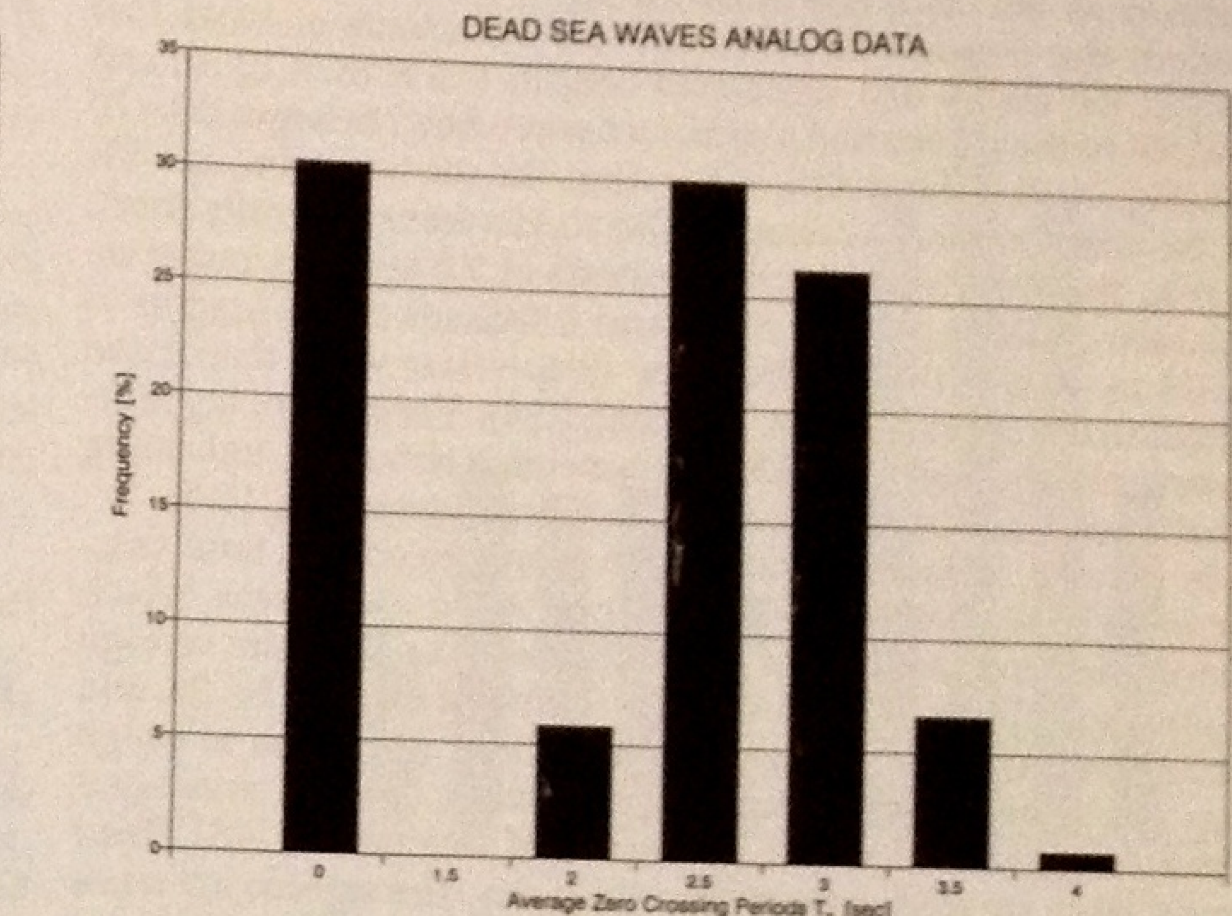

Figure 10-4 Analog data measurements; histogram of average zero crossing periods (T_Z). To complete the histogram to 100%, the value for calm seas was included.

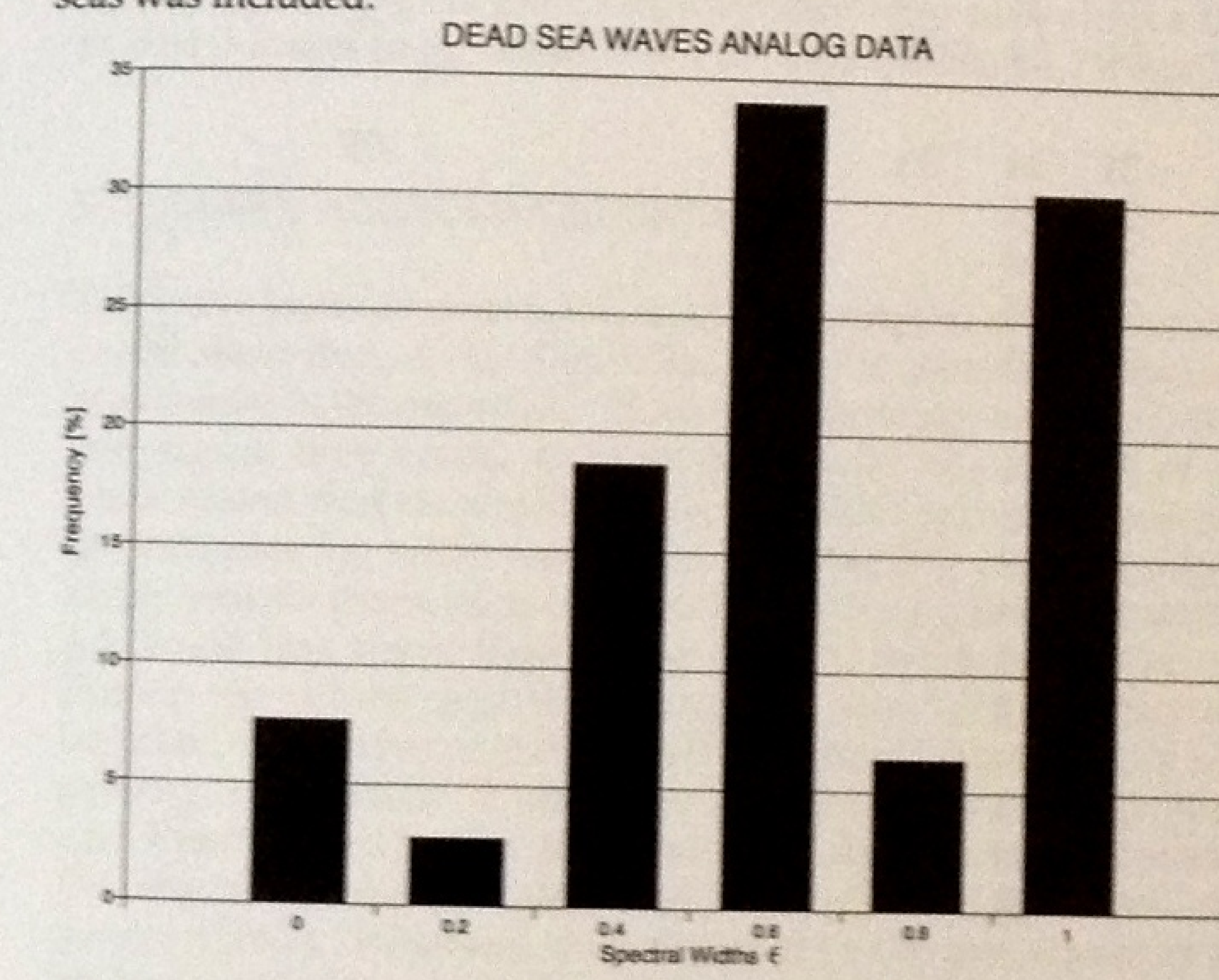

Figure 10-5 Analog data measurements; histogram of spectral width (ε). To complete the histogram to 100%, the value for calm seas was included.

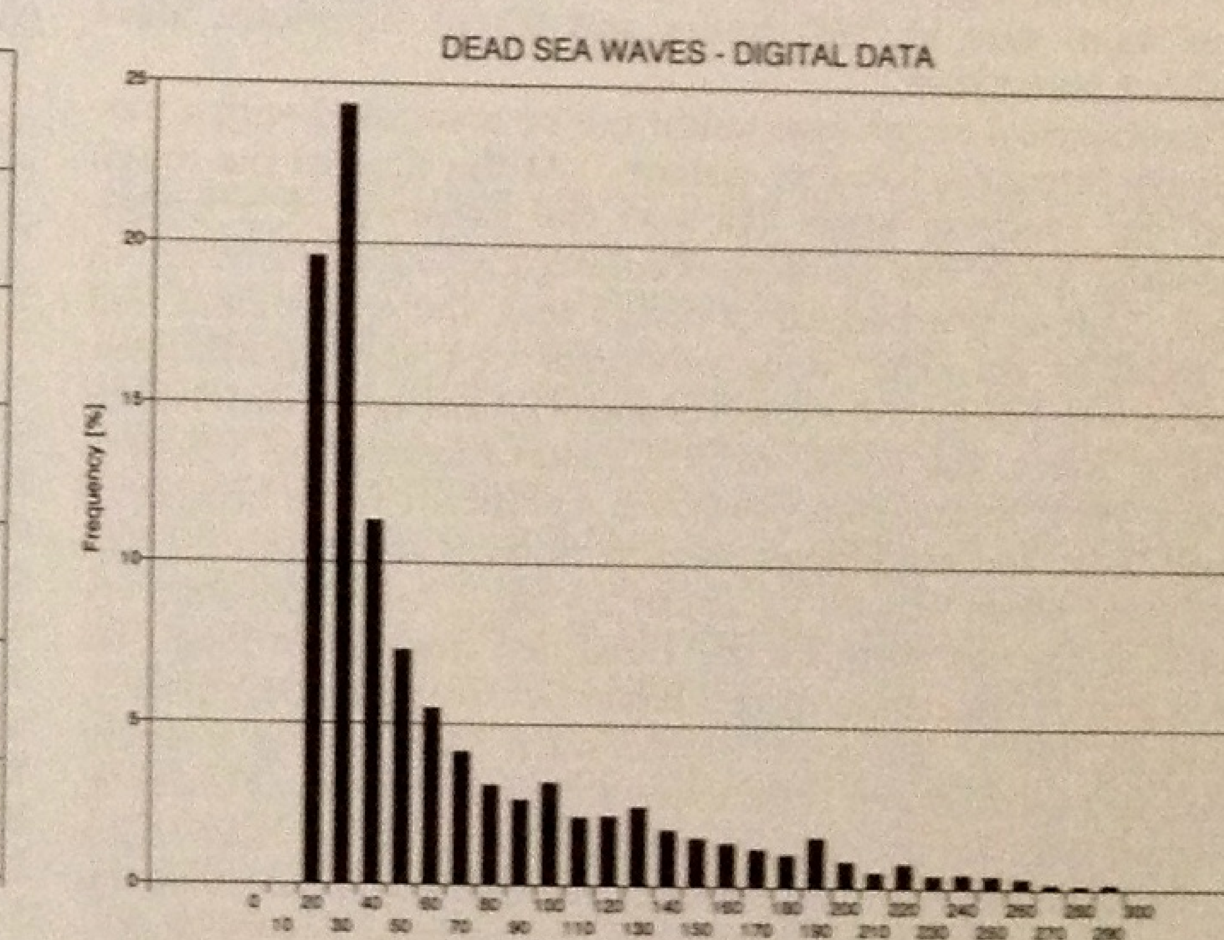

Figure 10-6 Digital data measurements; histogram of significant wave heights (H_S).

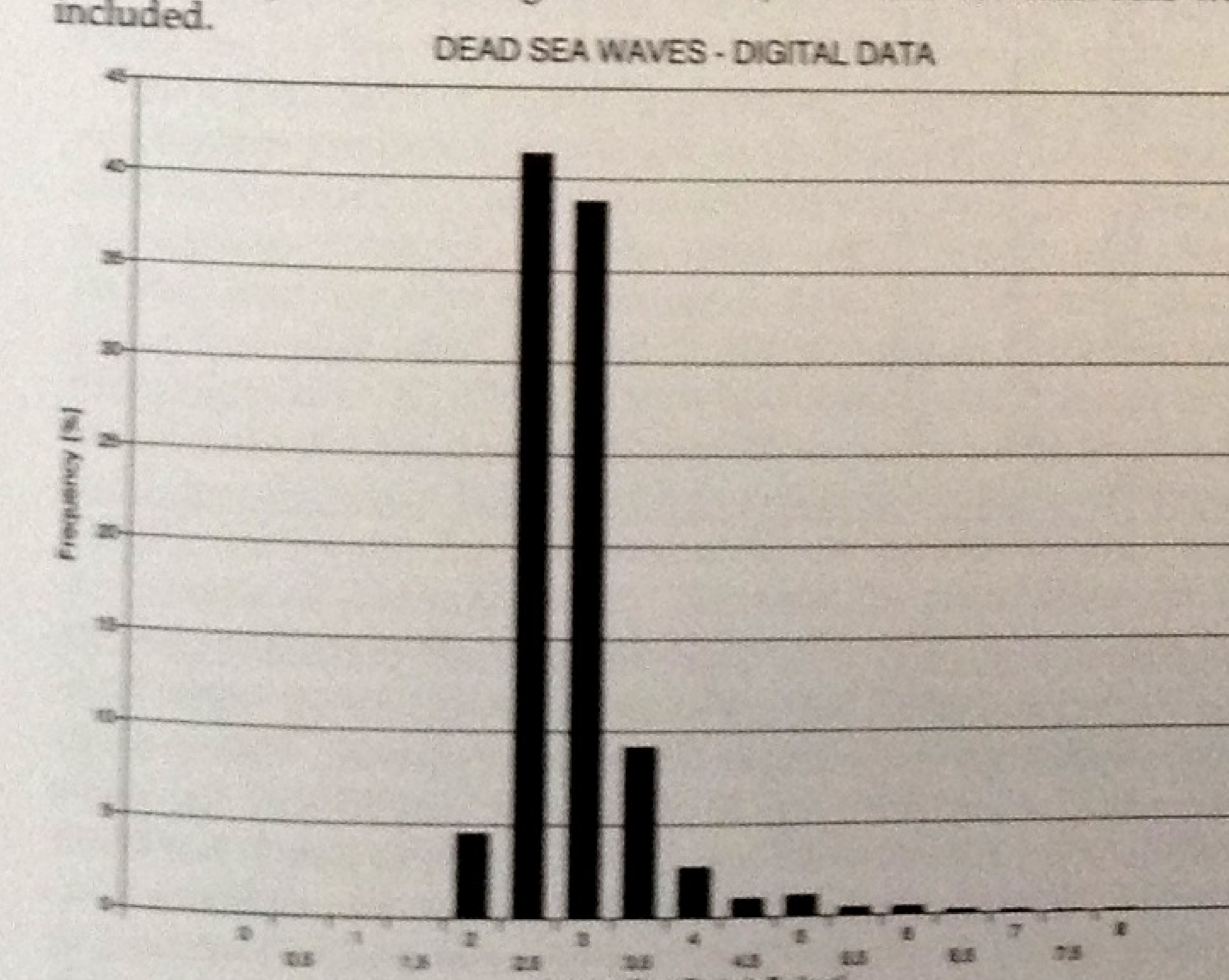

Figure 10-7 Digital data measurements; histogram of average crest periods (T_C).

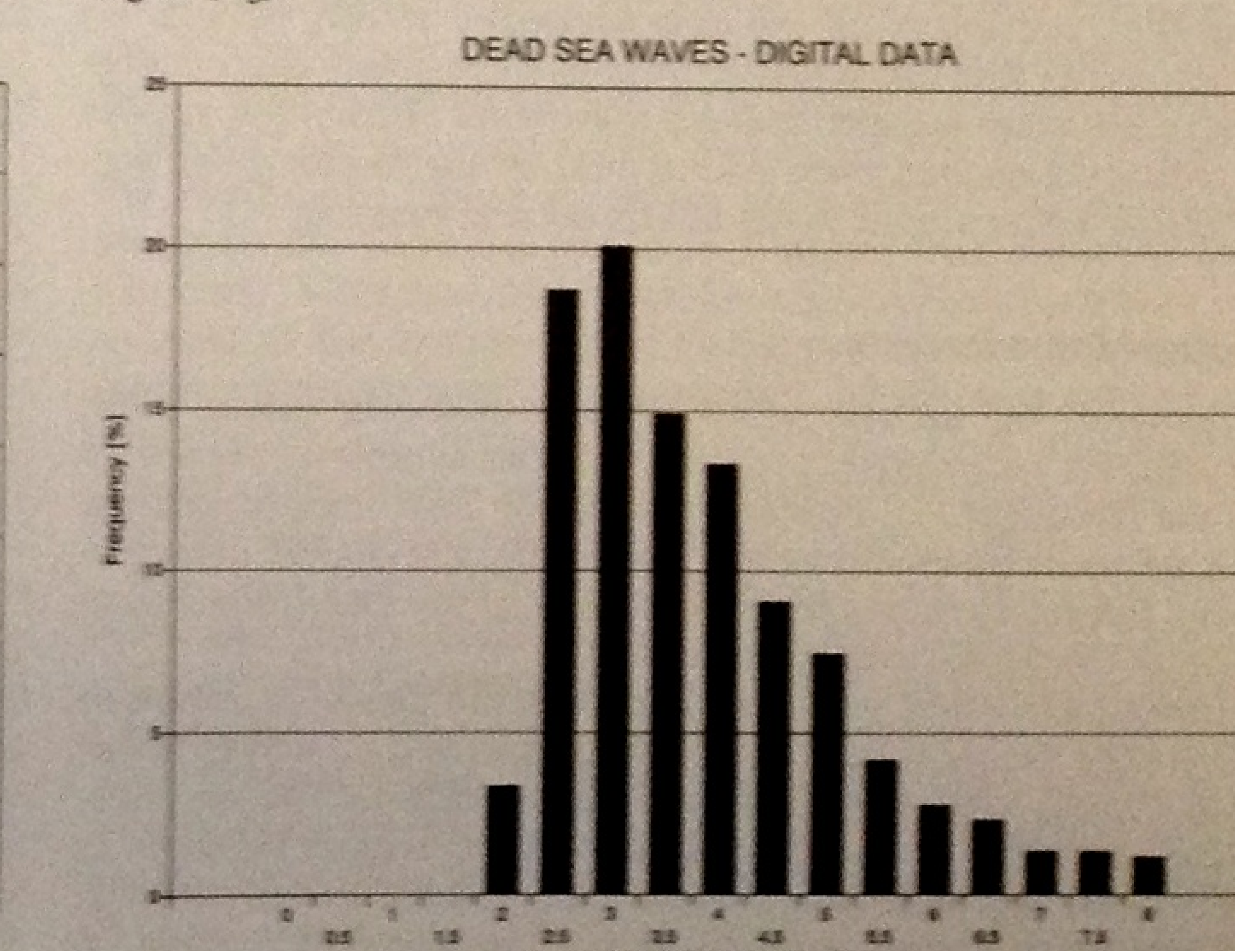

Figure 10-8 Digital data measurements; histogram of average zero crossing periods (T_Z).

defined as waves lower than 10 cm. During this particular period, the autumn of 1982, our measurements showed that 30% of the waves had significant heights lower than 10 cm and that 5% of the waves had significant wave heights larger than 70 cm (Fig. 10-2). About 30% of the time, the sea was calm, and 5% of the time the sea was rough. The waves were generally short, that is, they had average crest periods of 2.5 seconds and average zero crossing periods of 2.5 and 3 seconds (wave lengths of 10–14 m, as determined from the deep-water wave dispersion equation $L = (g/2\pi)T^2$, Figs. 10-3 and 10-4). For most of the measurements, the spectral width parameter is about 0.5, indicating a balanced combination of short and long waves (Fig. 10-5).

In general, calm seas lasted for long periods of time (e.g., Table 10-1, November 17–21), as opposed to rough seas, which lasted for short periods of time, that is, 8 to 12 hours of high waves (e.g., Table 10-1 on October 29, November 9, 16, 28, and December 24). The change from relatively calm seas to rough seas could be rather abrupt. For instance, the sea was completely calm at 1600 and at 2000 hours of October 28, 1982. Four hours later, by midnight of the same day, the significant wave heights measured 76 cm, and by 0400 hours, the significant wave heights reached 87 cm, with individual waves as high as 140 cm (from $H_{max}=1.6 \bullet H_S$). Again, on November 9, we measured calm seas at 0800 hours and 80-cm significant wave heights 4 hours later.

The observed rough seas could not be associated with a particularly intensive weather pattern. At the time of the rough seas, the synoptic maps showed the presence of a trough extending from the Arabian Peninsula toward the coast of Israel. During the periods of rough seas, the winds measured on shore at En Gedi were moderate (4–8 m/s) northerlies. Given a wind of 7 m/s, a fetch of about 35 km, and a duration of about 4 hours, the CERC-SPM (Coastal Engineering Research Center, 1984) nomogram predicted significant wave heights of about 75 cm and significant wave periods of about 4 seconds (a significant wave length of about 25 m). As a corollary, we looked at the sea state on the Dead Sea during the time that fronts and depressions crossed Israel (for example, December 5, 8, and 31, 1982). We could expect some fairly strong westerly winds to be associated with these weather patterns. However, as we pointed out previously, western winds do not have much of a fetch on the Dead Sea. Indeed, as expected, at the site of the wave gauge, these depressions did not seem to have a significant effect on the wave heights of the Dead Sea.

By averaging the data for a particular time, regardless of the date (e.g., average of all the data measured at 1400 hours), we attempted to find out whether there is a consistent diurnal pattern in the wave regime. Indeed, the results (Table 10-2) appear to indicate a diurnal cycle with a peak in the morning and significantly lower waves in the afternoon and evening.

Table 10-2 Diurnal variations of analog wave data (significant wave heights in cm)

Hour	N	Average ± St. Dev.
0000	65	23 ± 20
0400	68	28 ± 20
0800	65	30 ± 20
1200	67	25 ± 20
1600	63	13 ± 17
2000	64	14 ± 15

Table 10-3 Number of 10-minute digital records per day, 1983

Day	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
01		24	24	23						
02		24	24	24						
03	24	24	24	17						
04	24	24	24	24				07		
05	24	24	23	24				11		
06	24	24	11	24				05		
07	24	24		24						
08	24	24		24						
09	24	24		24						12
10	24	24		24						24
										03
11	24	24		10						
12	24	13								
13	24	24								
14	24	24								
15	24	24								
16	24	24								
17	24	24								
18	24	24				08				
19	24	24				24				
20	24	24				24				
21	24	24	07			06				
22	24	24	24							
23	24	24	24							
24	24	24	24							
25	24	24	24							
26	24	24	24							
27	24	24	24							
28	24	24	24							
29		24	20							
30		24	24							
31	24									

Digital Measurements

In general, the second series of measurements (Table 10-3), though still incomplete, provided a better sample of the waves on the Dead Sea. Climatologically, these data complement the first series of measurements. Essentially, the digital data provided information on the wave climate of the Dead Sea during parts of the winter and spring of 1983.

During the winter and spring of 1983, the Dead Sea appeared to be very active (Fig. 10-6). No calm seas (i.e., waves lower than 10 cm) were observed, and almost 50% of the measurements consisted of waves with significant heights between 20 and 40 cm. About 19% of the records indicated waves with significant heights above 1 m, 3% above 2 m, and 0.75% above 2.5 m. The last group includes individual waves with maximum heights of as much as 4 m. The average crest periods (Fig. 10-7) show that most of the waves were short—2.5 to 3 s (10 to 14 m long)—although some longer waves were present. The average zero crossing periods (Fig. 10-8) indicate that 83% of the wave periods were between 2.5 and 5 s (10 to 39 m long), but there were also a relatively large number of longer waves, some even as long as 8 s (100 m). Thus, we observe a sea combined of short waves riding on top of some long waves, a situation that

is also indicated by the spectral width distribution (Fig. 10-9). In the zero crossing distribution, a number of records (90 out of 1,890) indicated even longer waves; however, these were discarded as unreliable since, as shown previously, no such waves could develop on the Dead Sea.

In view of the data distribution (Table 10-3), we investigated the wave climate during different months, i.e., February, March, April, and May. We did not find significant differences between the months. An investigation of the diurnal variation of the wave heights (Table 10-4) showed once more that the highest waves occurred after midnight, between 0100 and 0300 hours, whereas the lowest waves occurred during the afternoon, between 1400 and 1600 hours.

The amount of digital data enabled us to test in greater detail another feature that appeared in the analog data, namely, the abrupt change from calm to rough seas. Table 10-5 shows selected cases of wave development in the Dead Sea. For every occurrence, the table shows the hour by hour significant wave height increase from the minimum to the maximum height. Thus, 00 hours is not the time of day but the starting point of the minimum wave field. Apparently, very rough seas characterized by significant waves higher than 2 m (maximum individual waves higher than 3 m) could develop in as short a time as 2 or 3 hours (e.g., Table 10-5, February 10, March 13, April 1).

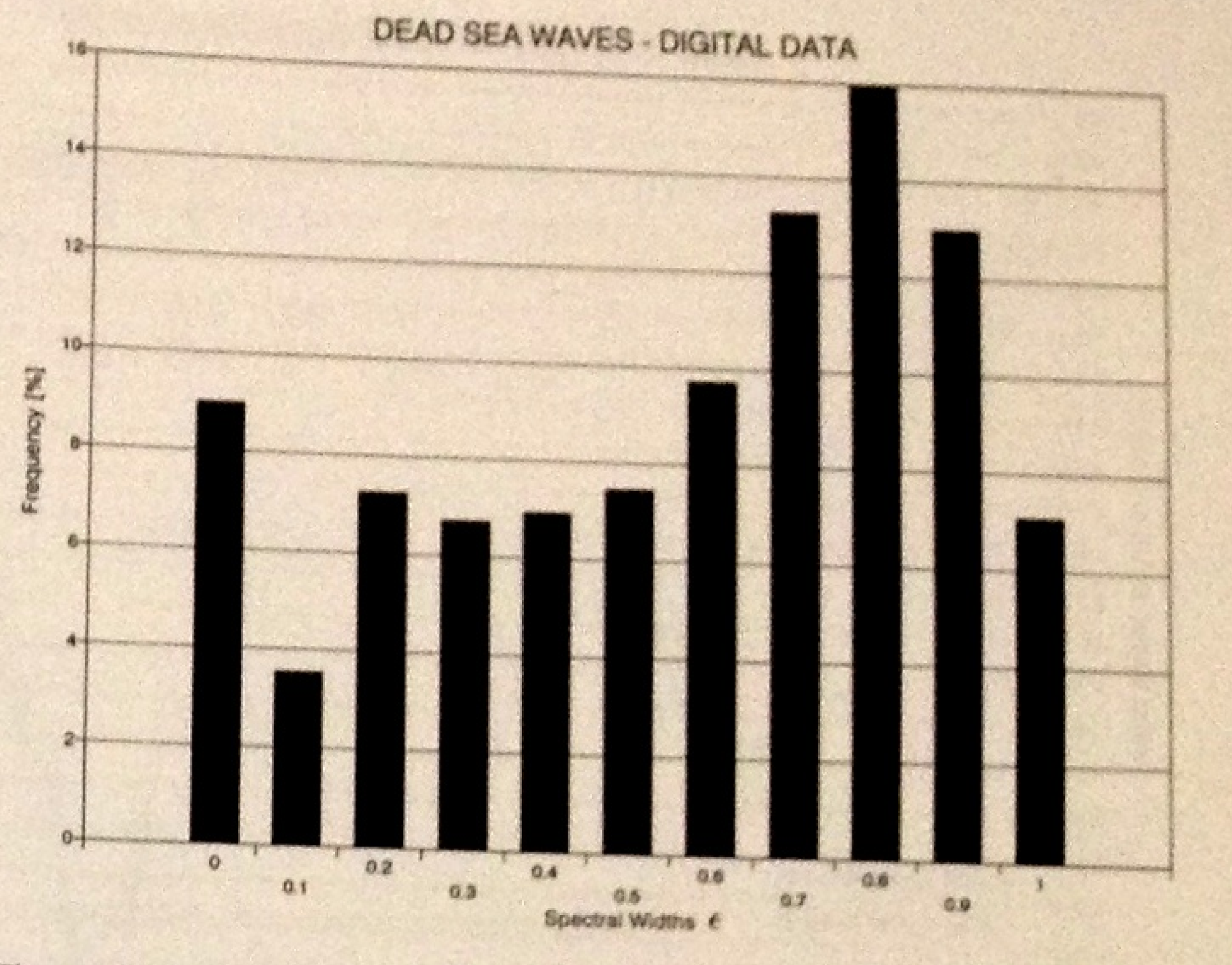

Figure 10-9 Digital data measurements; histogram of spectral width (ε). To complete the histogram to 100%, the value for calm seas was included.

SUMMARY AND CONCLUSIONS

The wave measurements we analyzed comprise a unique series in the sense that, on the Dead Sea, no wave measurements have previously been recorded. However, since they are a very limited series, they could, at most, be viewed as a display of the phenomena that occurred during a limited period of time and an indicator of what can occur. The analog and the digital series complement each other in time. They present us with a relatively low wave field in the autumn and a far higher one during the winter and the spring. In view of the connection between the waves and the weather pattern, this is hardly surprising, and indeed it was already reported as such by Neev and Emery (1967). Our measurements showed that the size of the waves is much higher than that reported by Neev and Emery (1967). Whereas, they reported the largest waves as 1.1 m high and 10 m long (i.e., 2.5 s), we found waves that can reach a height of at least 3 m and have periods of up to 8 s (i.e., 100 m long). Therefore, their statement that the waves on the Dead Sea are lower than those on Lake Kinneret is incorrect.

The CERC-SPM (Coastal Engineering Research Center, 1984) nomogram predicted significant wave heights of 1.7 m, significant periods of 5.5 s, and wave lengths of 45 to 47 m. Thus, the nomogram-computed waves were much lower and much shorter that the ones we measured directly. The same nomogram was also used to predict the waves on Lake Kinneret (Boguslavski et al., 1988), which had a maximum height of 1.4 m, periods of 4.3 s, and lengths of 29 m. Once more, these were far below the wave heights of 3 m reported by Neev and Emery (1967). However, there appear to be no records of wave measurements of Lake Kinneret. Because the population on the shores and the surface of Lake Kinneret is far larger than that on the shores and the surface of the Dead Sea, the visual reports from Lake Kinneret are far more frequent. Introducing corrections for the "closed sea effect" (e.g., Leenknecht et al., 1992) resulted in a marginal increase in the Dead Sea wave heights and lengths. Thus, the nomograms appear to underestimate the wave field on the Dead Sea as well as on Lake Kinneret. Incidentally, this makes our criterion for the exclusion of certain wave measurements more conservative.

A number of factors are not taken into account by either the CERC-SPM (Coastal Engineering Research Center, 1984) or the Leenknecht et al. (1992) nomograms. One such factor is the orography of the two lakes and, in particular, the vertical components of the winds, which could be significant but find no expression in the wind measurement records. Other factors could be short-period wind variations (wind measurements are usually integrated over a time span), gusts, or currents at sea. One particularly well-known factor, and the one mentioned by Neev and Emery (1967), is the density difference between the two lakes (Lake Kinneret, essentially 1; the Dead Sea, essentially 1.3) and the open sea (essentially 1.02). Huss et al. (1986) show that, for a given wind, the transfer of energy to the surface currents results in a slower current in the Dead Sea than in the open ocean. Similarly, we may expect intuitively that, for the same conditions wind force, fetch, duration, and water depth), the waves developed in the Dead Sea should be lower than those developed in the open ocean or in Lake Kinneret, since the potential energy for a given wave height depends on the water density. Neev and Emery (1967) attempt to relate their observation that the waves on the Dead Sea are lower than those on Lake Kinneret to the higher density of the waters of the Dead Sea. However, as we have shown previously, the waves in the Dead Sea are in fact higher than those on Lake Kinneret. Moreover, Neev and Emery (1967) did not take into account all the factors related to the growth of the wave field (fetch and water depth, in particular), which, as a rule, would result in smaller waves in Lake Kinneret. Thus, although the density of the waters may affect wave development in the Dead Sea, this was not proven by Neev and Emery (1967).

The abrupt development of the rough seas, also reported by Neev and Emery (1967), as well as a similar feature of the wave field on Lake Kinneret, was confirmed quantitatively by our measurements. This effect can be related to the wind speed and wave frequency (e.g., Phillips, 1957; Miles, 1957; Inoue, 1967), as well as to specific local factors, such as the vertical component of the winds, the density of the waters, and the currents in the sea.

Finally, the periodicity of the wave field was also reported by Neev and Emery (1967). They report a mirror-like sea until

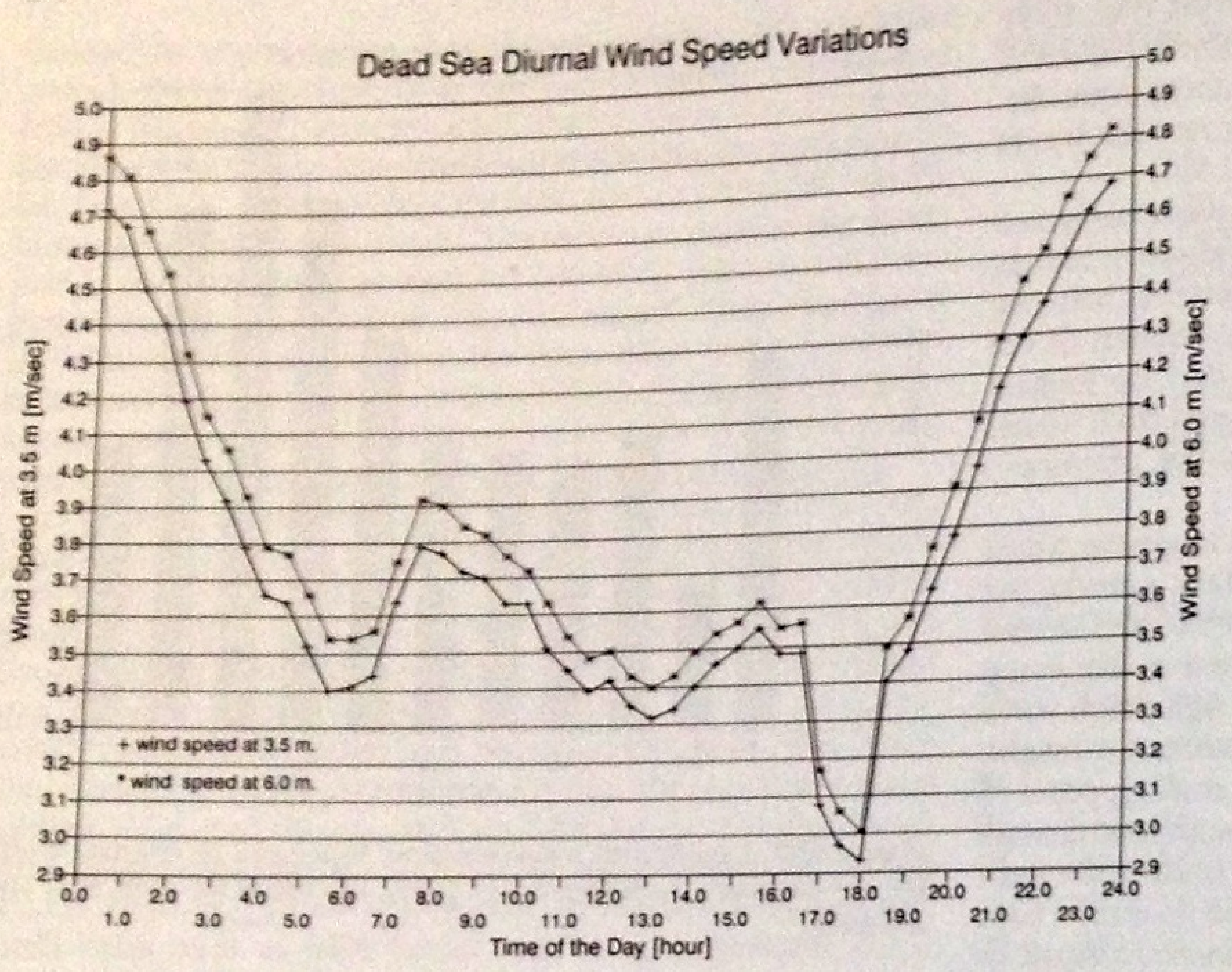

Figure 10-10 Average diurnal wind variation from winds measured at sea November 8, 1983 to August 19, 1984 at the position in Figure 10-1: +, at 3.5 m above the sea surface; *, at 6 m above the sea surface.

Table 10-4 Diurnal variation of digital wave data (significant wave heights in cm)

Hour	Average ± St. Dev.
00	77 ±62
01	81 ±66
02	81 ±65
03	81 ±64
04	77 ±60
05	77 ±62
06	71 ±56
07	66 ±56
08	59 ±51
09	62 ±54
10	62 ±57
11	58 ±50
12	51 ±45
13	44 ±45
14	38 ±38
15	34 ±33
16	38 ±38
17	40 ±42
18	40 ±40
19	47 ±42
20	50 ±45
21	53 ±40
22	57 ±44
23	66 ±57
All	59 ±54

about 1000 hours, followed by a gradual intensification of the wave field, which reaches its peak at about 1500 hours and then dies out to become calm again at about 2000 hours. It is not clear from their report whether the sea stays calm throughout the night, i.e., between 2000 hours and 1000 hours the following day. The questions is, what is the reason for this periodicity? One obviously periodic driving force could be the sea breeze. Neev and Emery (1967) report that the winds over the Dead Sea are diurnally periodic: calm in the morning until 1000 hours, increasing to 1500 hours, and dying out by 2000 hours. According to Neumann and Stanhill (1978, p. 53), "One of the outstanding meteorological features of the Jordan Rift in summer is the arrival 'in force' in the afternoon hours of the Mediterranean sea breeze." Their investigation shows that the Mediterranean sea breeze arrives at Lake Kinneret in the afternoon hours and because of the orography of the region surrounding Lake Kinneret, it is amplified to twice and even two-and-a-half times the velocity near the Mediterranean shores. Thus, the breeze can reach speeds of 10 to 15 m/s and is the driving force behind the daily summer afternoon storms on Lake Kinneret. Weiss et al. (1987), as well as Weiss and Cohen (1988), mention that the high evening air temperatures on the Dead Sea, as well as the wind peaks occurring between 1700 and 1900 hours, are due to the Mediterranean breeze, but present no analysis to demonstrate their statements.

However, as we have seen, although our measurements show that the wave field is diurnally periodic, we observed the calmest seas in the afternoon and the highest seas past midnight at about 0200 hours, contrary to Neev and Emery (1967). Therefore, we decided to analyze the available wind measurements on the Dead Sea (i.e., November 8, 1983 to August 19, 1984). The data suffer from many gaps, and as a time series, they are not suitable for spectral analysis. A simpler and more superficial approach is to average the wind velocity for every half hour of the day, regardless of the date of the measurement (similar to the procedure we applied to the wave measurements). Our results (Fig. 10-10) show that the wind speed reaches a maximum around midnight and a minimum during the late afternoon hours. Thus the diurnal variations in the wind speed over the Dead Sea do not resemble those reported for Lake Kinneret, and, climatologically, fit in with the diurnal wave height as reported herein.

The present investigation has indicated a number of discrepancies between the wave field as reported by Neev and Emery (1967) and our own measurements. Far from trying to belittle the pioneering work of Neev and Emery (1967), to whom we are deeply indebted, we intend to stress the importance of objective prolonged measurements as opposed to sporadic observations. Therefore, we expect that an even longer and more precise series of wave measurements on the Dead Sea may yield different results than those we have presented.

Table 10-5 Examples of the rate of wave development in the Dead Sea (significant wave heigths in cm)

Date	Time from Minimum to Maximum (hours)												
	00	01	02	03	04	05	06	07	08	09	10	11	12
09 Feb	14	15	15	24	50	92	112	201	197	236	240		
10 Feb	12	15	20	66	208	185	215	281	245	219	283	219	286
13 Mar	16	19	197	234	240	243							
20 Mar	14	19	23	53	143	183	262						
29 Mar	14	17	105	169	195	220							
30 Mar	15	20	20	110	155								
31 Mar	17	20	71	160	157	219							
01 Apr	17	17	120	216									
30 Apr	25	89	92	98	228								
01 May	27	58	44	84	117	151							
02 May	16	18	40	90	115	183							
05 May	19	19	26	26	54	58	168	231					
09 May	22	23	50	43	168	255							

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