2

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Coastal Hydrographics Techniques: Data Report for Support of the Airborne Bathymetry System at CERC FRF, Duck, N. C.

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Stennis Space Center, Mississippi 39529-5004

ABSTRACT

Coastal Hydrographics Techniques (CHT) personnel in support of the Airborne Bathymetry System (ABS) traveled on two separate occasions to the CERC FRF at Duck, N. C., to provide ground truth data for the overflights of the system.

The following data report gives a preliminary look at the data and provides some preliminary analysis and simple calculations using the collected data for both CHT and ABS applications.

ACKNOWLEDGEMENTS

Great appreciation is expressed for the help and assistance offerred by the CERC FRF personnel at Duck, N. C.. Coastal Hydrographics Techniques is funded by OP 096, Program Element 63704N.

DATA REPORT FOR THE COASTAL HYDROGRAPHICS TECHNIQUES SUPPORT OF THE AIRBORNE BATHYMETRY SYSTEM AT CERC FRF PIER AT DUCK, N.C.

L. Estep, L. Hsu, and R. Arnone

INTRODUCTION

The Defense Mapping Agency (DMA) has provided support for the developement of the Airborne Bathymetry System (ABS). Five flights for fiscal year 1988 were planned by NORDA in conjunction with DMA and the Naval Oceanographic Office (NAVOCEANO). These test flights of the system were to take place at selected areas chosen for their water optical quality, bottom type and reflectivity, and bathymetry database availability.

A site selected for the ABS overflights was the Army Corps of Engineers Coastal Engineering Research Center (CERC) Field Research Facility (FRF) at Duck, North Carolina. This ocean engineering research center provides an ideal area for test overflights due not only to the water optical quality variability but, also, because the facility research mandate provides valuable supporting data for understanding the impact that environmental factors have as noise sources in the return signals of the HALS laser sounder. The CERC facility routinely measures, collects, and archives wave spectra and direction, prevailing currents, weather conditions, bottom sediment types, high accuracy bathymetry, tidal information, and sediment transport Appendix A provides ancillary information about CERC FRF and the archival database present.

To support its investigations, the FRF utilizes a 6.1 by 561 meter long pier that extends from behind the dune line seaward to about the 7 meter depth contour. At the terminus of the pier is stationed an air-conditioned van which can be used to house instruments for experiments conducted near the end of the pier. Locations on the pier are enumerated in feet from a baseline located landward of the laboratory building and normal to the pier centerline. The laboratory building includes offices, a kitchen, library, computer center, a multipurpose area, and a diving locker [1].

In two separate ABS field support excursions to the CERC FRF at Duck, data was collected for the purpose of providing ground truth for the P-3 overflights. The first field study ran from 14 June 1988 to 19 June 1988 inclusive with the overflight occurring on 18 June 1988. The second field study ran from 14 August 1988 to 18 August 1988 inclusive with the overflight occurring on 17 August 1988.

FIELD INSTRUMENTATION AND DATA COLLECTED

The instrumentation used for determining the ocean optical properties was a spectroradiometer that was designed and built by Research Support Instruments (RSI). The instrument measures irradiance using a cosine collector at five channels of radiant energy input. Four of the five channels are equivalent to the channels of the Coastal Zone Color Scanner (CZCS). One channel is at a spectral benchmark that allows interpolation of the measurements made at this wavelength to other wavelengths (see Appendix B for wavelength values and comparison to the CZCS wavelengths). The spectroradiometer data is read from the panel meters in the control box. Upwelling and downwelling irradiance, pitch, roll, and water temperature are recorded at distinct depths increments.

Optical measurements were collected at three separate stations on the first trip and two stations on the second trip (with readings taken twice at one station). These data were taken along the pier, seaward, with the RSI instrument. Table 1 provides relevant station information. The data collection procedure involved utilizing a rigid support frame that allowed a block to be hung over the handrail of the pier. Through the block ran the support line and electrical cable for the instrument The spectroradiometer was lowered to a position just above the water surface and initial readings collected These readings consisted of the upwelling irradiance and the downwelling irradiance. Once completed, the instrument would be placed below the surface of the water and a second set of readings would be recorded From these data, the spectral transmission of the interface could be estimated Moreover, spectral estimations of the surface reflectance, water leaving irradiance, and absorption of the surface water layer could be made. Once the second set of readings was completed, the instrument was lowered incrementally until near the bottom. From these data, the diffuse *attenuation coefficient* can be reckoned and the spectral bottom reflectivity estimated. Bathymetric information on the station was recorded. The three stations taken were at 660, 1220, and 1900 feet respectively for the first data set. The second data set comprises data taken at 1220 (two datasets on the same day at different times) and 1900 feet on the pier.

The primary interest the water optical data has is the impact the multifarious environmental factors might have on the active portion of the ABS, the HALS laser sounder, return signals. Additionally, these optical measurements could be used to improve the bathymetry algoritms used in the passive subsystem of the ABS, the NORDA scanner.

DATA REDUCTION AND DISPLAY

The data reduction procedure for each plot in the following set of graphs will be briefly discussed.

The spectral transmission of the interface was estimated by looking at the downwelling above the surface versus the downwelling below the surface. Because wave action alternately increases and decreases the overlying water layer thickness, the measurement is somewhat difficult to make due to the rapidly varying readings obtained. Nonetheless, by looking at the maxima and minima readings obtained and taking an intervening reading, some reasonable approximation can be obtained. It is to be noted that the layer of intervening water between these measurements is not infinitesimally thin. Thus, some absorption invariably occurs. No provision for correcting the transmission for this absorption is made in the relevant plots. Figure 1 exhibits the spectral transmission of the interface for the three pier stations for the first Duck field excursion. Relevant data for second Duck field study was not recorded.

The reflectivity of the naviface could be estimated by comparing the downwelling and the upwelling irradiance while the instrument is above the surface. Care must be taken here since the instrument ought not shadow itself while in the process of extracting a reading Moreover, as with the transmission *measurement aforementioned,* the collimated component represented by the direct sun will affect the measured values. That is, the transmissivity and reflectivity of the naviface is dependent on the solar angle. Theoretically, one could subtract the transmissivity from unity and obtain a value for reflectivity simply through conservation of energy considerations (provided no absorption occurs) However, emanating from below the water surface through the air-water interface, is light due to the water column. This water leaving irradiance is embedded in the surface reflectance flux and, thereby, is part of that which is measured as reflectivity. Figure 2 shows the reflectivity of the interface for the first field data set. Figures 3 and 4 show the percentage of water leaving irradiance for the first data set and for the third station of the second data set when compared to the overall light leaving the air-water interface.

If it is certain that some absorption took place in the interface region, then since the sum of reflectivity, transmissivity, and absorption ought to equal unity, one is able to estimate the amount of absorption in the surface layer of the interface. Figure 5 shows this kind of calculation for the first Duck data set.

The irradiance reflectances were measured for each level taken at each station. Notice at the top station, above the interface, this amounts to measuring the reflectivity of the interface. At the bottom, if such a measurement could reasonably be made, this data would allow the reckoning of the bottom reflectivity. The air-water interface and the benthic interface are actual (real) interfaces. The intervening ratios of the upwelling to downwelling are not of real interfaces, therefore, they will be referred to hereafter as irradiance ratios. The irradiance ratios, treating channel and depth as the independent variable by turns, are shown for each station in Figs. 6-20. The upwelling and downwelling diffuse attenuation coefficient (or 'k') was computed as a function of depth and channel. Figures 21 through 44 show these results.

The bottom reflectivity measured by the laboratory reflectometer on the bottom samples taken at Duck for the different stations is shown in Tables 2 and 3. The bottom reflectivity as calculated by a simple bulk properties model and by linear regression of the irradiance ratios as a function of depth for a given wavelength are compared in Figs. 45 through 50 for the Duck study. The bulk properties model is provided as Appendix C. The weakness of the model is in assuming the diffuse attenuation coefficients, or k values, for both the upwelling and the downwelling light streams for the last level above the bottom, to be adequate for the calculation.

DISCUSSION OF DATA

The discussion that follows is abbreviated and will be expatiated in a follow up report In the following discussion, the term 'channel' refers to the specific wavelengths of the sensor filters possessed by the spectroradiometer. See Appendix B for details

In the discussion above, Fig 1 was shown to exhibit the transmission of the interface. For a calm interface, a calculation may be made using the well known Fresnel formulae. If we assume a refractive index of 1.34 for sea water, Figs. 51 and 52 give the results for various angles of incidence in air and water respectively. Notwithstanding, a calm interface is hardly realistic. Gordon (2) has given the time averaged reflectances for various windspeeds from 0 to 19 m/sec. Fig 53 gives the transmittance of the air-water interface as a function of windspeed. Gordon (2) assumes that the crosswind and upwind slope parameters may be represented by a single Gaussian distribution of slopes. This is a simplifying assumption. Comparing Fig 1 results to Fig 51 shows obvious discrepancies For an observation angle of zero degrees, the transmittance ought to be a little less than 98 % However, Fig 1 provides smaller values Furthermore, since there is some reflection from the naviface for light coming up from below, this gets summed with the light the downwelling sensor on the RSI instrument sees transmitted through the interface This adds a small positive bias to the measurement of the transmission through the air-water boundary. The plots in the graph shown in Fig. 1 have not been corrected for the bias mentioned.

Fig 2 exhibits the reflectivity for the first Duck data set. Again, the values expected from Gordon (2) do not compare well with the measured values. For a nadir observation angle, the reflectance of the naviface ought to be a little over 2 %, even for windspeeds up to 16 m/sec.

Figs 3 and 4 show the water leaving irradiance (water column light) for the three stations associated with the first Duck data set and for the third station of the second Duck data set. An interesting result here is the apparently high percentage of 'embedded' flux or water leaving irradiance in the total light that leaves the interface upward. Station two exhibits an improbable excess of water leaving irradiance. Three factors may enter here and in other data results to cause these kind of erroneous readings. First, there can be simple reading errors in recording the measurement from the panel meters, or simply errors involved in choosing a nonrepresentative reading when the readings on the panel meter fluctuate rapidly. Secondly, there was no deck cell coupled with the instrument to allow a way to normalize the changing lighting conditions extant while the measurements were being made. Thirdly, the instrument is lowered into the water below the surface far enough to have the instrument covered completely even with the presence of waves. The thickness of the water layer is therefore a function of the wave action present. Since there is a water layer to propagate across, the readings found for the upwelling below the interface may not include the attenuation near the surface due to suspensoids, and transmission through the interface. However, the total light off the water surface will include such effects. The plots of the reflectivity seen in Fig. 2 are not corrected for the water leaving irradiance fraction.

Fig. 5 provides an estimation of the absorption of the water layer when combined with the transmission and reflectivity of the interface. If we know the transmission and reflectivity, then the absorption can be found. An interesting result here is that station one in the first Duck data set exhibits negative absorption. Or, in other terms, light seems to be created in the water layer referred to. Beyond simply an error being made in taking the reading, this possibly may be due to the presence of suspended particulates in the water layer bracketed by the instrument in its first two measurement positions at the station. Station one was quite close to the beach area. This allowed the water to have a quantity of resuspended sediments near its surface layers. These suspensoids allowed for a good deal of backscattered light to be seen by the downlooking sensor above the interface and, yet, not picked up by the uplooking sensor below the water surface layer. This tended to inflate the reflectivity measured and reduce the apparent transmission. Fig 54 displays the excess percentage of irradiance at *station one* over 100 %. Figs. 6 through 20 provide the irradiance ratios for both Duck data sets as a function of both channel and depth There were some apparently aberrent measurements made in these data. For example, Fig. 18 shows the irradiance ratios for station three of the second Duck data set Here, the irradiance ratios exceed unity Ostensibly, the recorded values were in error.

Figs 21 through 44 provide the upwelling and downwelling diffuse attenuation coefficients (k's) as a function of channel and depth. By and large, the upwelling k's exceed the downwelling k's in value. Presumably, if the water mass were uniform, the upwelling and downwelling k's would be identical. Thus, the nonequivalence of these provides a rough gauge of the nonuniformity (stratification) of the water column.

Figs. 45 through 50 provide estimations of the bottom reflectance in two ways. First, the irradiance ratios as a function of depth are plotted and fit by a curve which allows a prediction of the bottom reflectance, for a particular channel, for the given depth. Secondly, the water mass is modelled and using as input the measured upwelling and downwelling k's as well as the depth of the station, the bottom reflectance is calculated for the channel in question. Again, some of the values obtained by these methods are simply too large. For instance, Fig 49 exhibits the bottom reflectivity estimation for station two of the second Duck data set. Obviously, the values are too high. Lyzenga [3] provides some bottom reflectivity values as a function of wavelength for sand, silt, shoal grass, and turtle grass from the Panama City, Florida area. Fig 55 shows Lyzenga's results. For a relatively light colored sand shown, the percentage of reflectance never exceeds 30 %.

Tables 2 and 3 provides the data sheets for the measured values of the reflectivity of bottom samples obtained at Duck for different distances along the pier. Certain distances match closely the three distances at which stations acquired data and the other distances provide some insight into the nature of the change of bottom reflectivity as one moves seaward from the laboratory building. The measurements were made in the laboratory using a Hunter Reflectometer Model 40D that uses either (or both) a green and blue filter to make 'whiteness' and/or reflectance measurements. Some agreement in the calculated and measured values can be seen by comparing the results for station 1. The filters used by the Hunter Reflectometer are wide-band. Thus, channels 1 and 2 will be covered by the 'blue' filter and channel 3 covered by the 'green' filter. Fig 45 shows the bottom reflectivity for station 1. Comparing channels 1 and 2 to the laboratory measurements in Fig. 56 for the 700 foot mark, the agreement is evident for the extrapolation of the irradiance ratios to the bottom. However, the respective values of channel 3 not only show different trends but have somewhat different values. The top-most plot in Fig. 56 shows the result of the Hunter-Judd whiteness equation. This gives a direct proportion scale from 0 to 100 for 'whiteness'. Interestingly enougn, the darker sediments at the end of CERC pier show a higher value of 'whiteness' than those closer to the shore. It appears something is awry here.

The disagreement between the measured and calculated values either by extrapolation or modelling possess can be due to the implicit assumptions that could be easily violated by a complex water mass. For example, in the extrapolation process, it is expected that the irradiance ratios vary smoothly with depth. This is obviously not the case. Hence, any extrapolation taken is done so at some risk. In the bulk properties model alluded to earlier on, there is the clear indication that the k's, both upwelling and downwelling, do not represent well enough the actual attenuation which holds in the vicinity of the bottom.

In order to carry the analysis a somewhat further and provide connection to the ABS HALS laser/receiver subsystem, Appendix D gives some relevant laser power and signal-to-noise calculations using the data found at station 3 for the Duck data set 1. Appendix E uses an algorithm due to Austin and Petzold (4) to calculate the k value for the upper surface of a water mass using a ratio of the water leaving irradiance at two CZCS wavelengths. This k value is then compared to the measured k value (see Figure 58). Appendix F exhibits the field data sheets themselves

FUTURE ANALYSIS EFFORTS

The data collected by CHT personnel at Duck CERC FRF, when used in conjunction with the results from the overflights of the ABS will allow analysis which will address the effects of the environment on the ABS signals. Beyond the ABS requirements analysis, further investigations into the applicability of the CZCS algorithm developed by Austin and Petzold for coastal waters would be very useful.

An aspect touched on in the above has been the reflectivity of the bottom sediments collected at Duck. Both laboratory measurements and some theoretical computations were utilized to obtain values for the reflectivity. It appears that very little actual work has been done on bottom sediment reflectivity. Yet, it is a very important parameter in the prediction and actual operation of many ocean optical systems in coastal waters. Further analysis in this direction is very much needed.

ACKNOWLEDGEMENTS

Great appreciation is expressed to the CERC FRF personnel at Duck, N.C., who made our field work pleasant and worthwhile.

REFERENCES

1. W. A. Birkemeier, et al. , A Users Guide To The Coastal Engineering Research Center's (CERC'S) Field Research Facility, Instruction Report CERC-85-1, Dept. of the Army, U. S. Army Corps of Engineers, May 1985.

2. Gordon, J. I., SIO Ref. 69-20, Univ. of Calif., San Diego, Scripps Inst. of Ocean. , 1969.

3. D. R. Lyzenga, 13th Int. Symp. on Rem. Sens. Env., ERIM Conference, July 1978.

4. Austin, R. W. and T. J. Petzold, " The Determination of the Diffuse Attenuation Coefficient of Sea Water Using the Coastal Zone Color Scanner", in Oceanography from Space, J.F.R. Gower, Ed.(Plenum Press, N.Y., 1981), pp. 239-255.

5. South African Ocean Colour and Upwelling Experiment, L. V. Shannon, Ed., Sea Fisheries Research Inst., Cape Town, 1985.

6. Duntley, S. Q., "Underwater Lighting by Submerged Lasers and Incadescent Sources", Scripps Inst. of Ocean. Final Report SIO Ref. 71-1, June 1971.

FIGURES

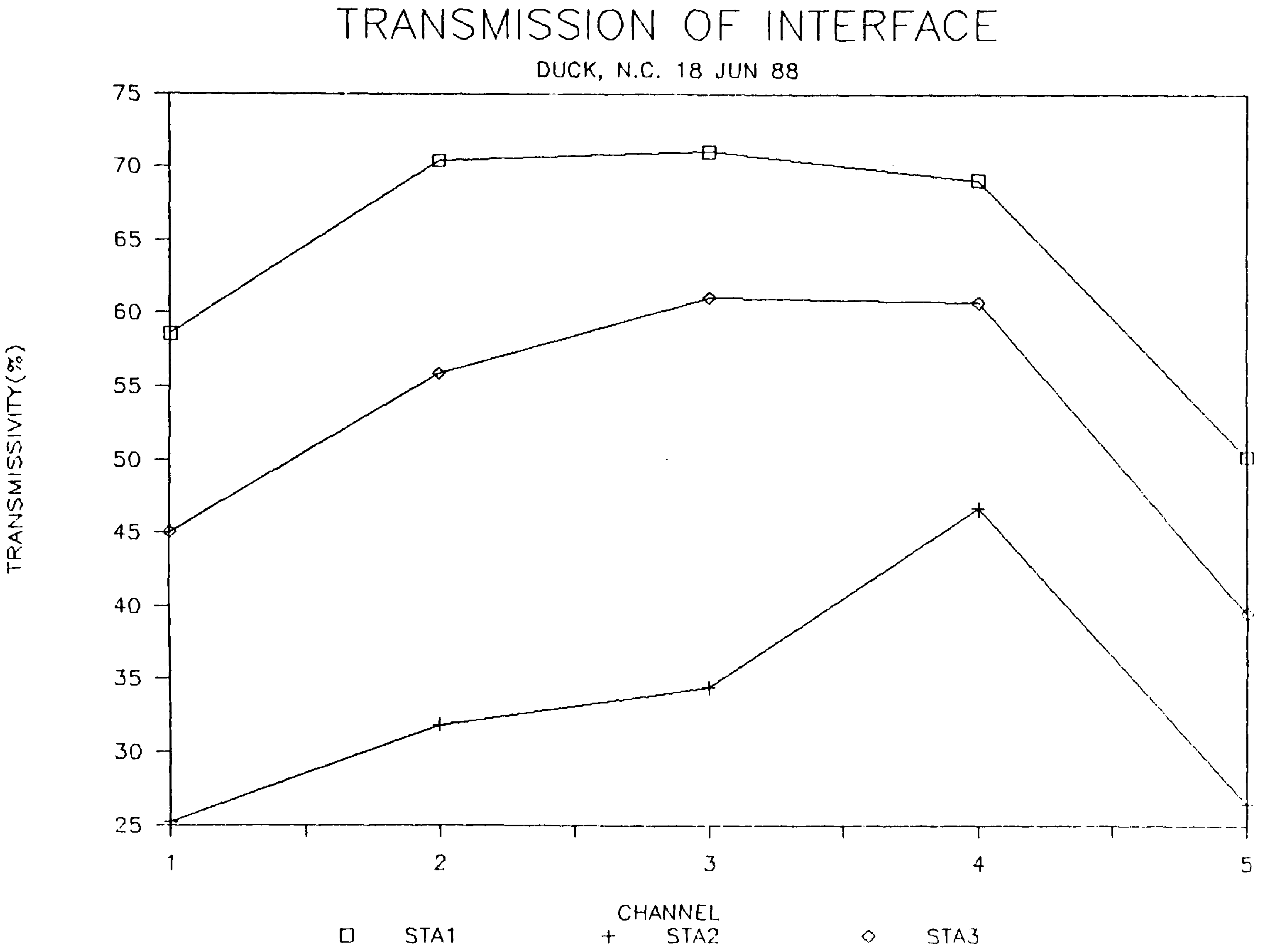

TRANSMISSION OF INTERFACE
DUCK, N.C. 18 JUN 88
TRANSMISSIVITY (%)
75
70
65
60
55
50
45
40
35
30
25
1
2
3
4
5
CHANNEL
□ STA1
+ STA2
◇ STA3

FIG 1

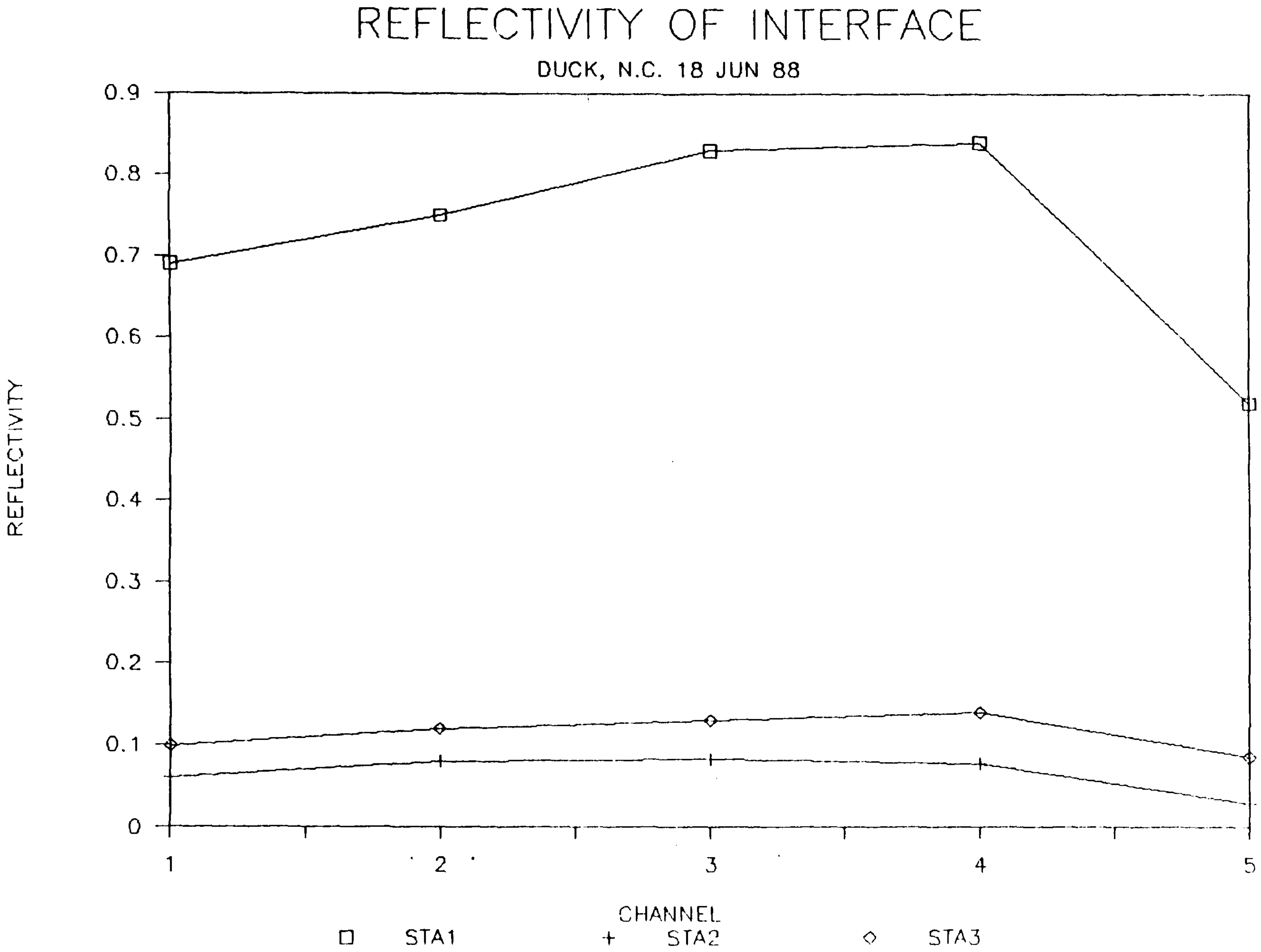

REFLECTIVITY OF INTERFACE
DUCK, N.C. 18 JUN 88
REFLECTIVITY
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
CHANNEL
□ STA1
+ STA2
◇ STA3

FIG. 2.

WATER LEAVING IRRADIANCE FRACTION

DUCK N.C. 18 JUN 1988

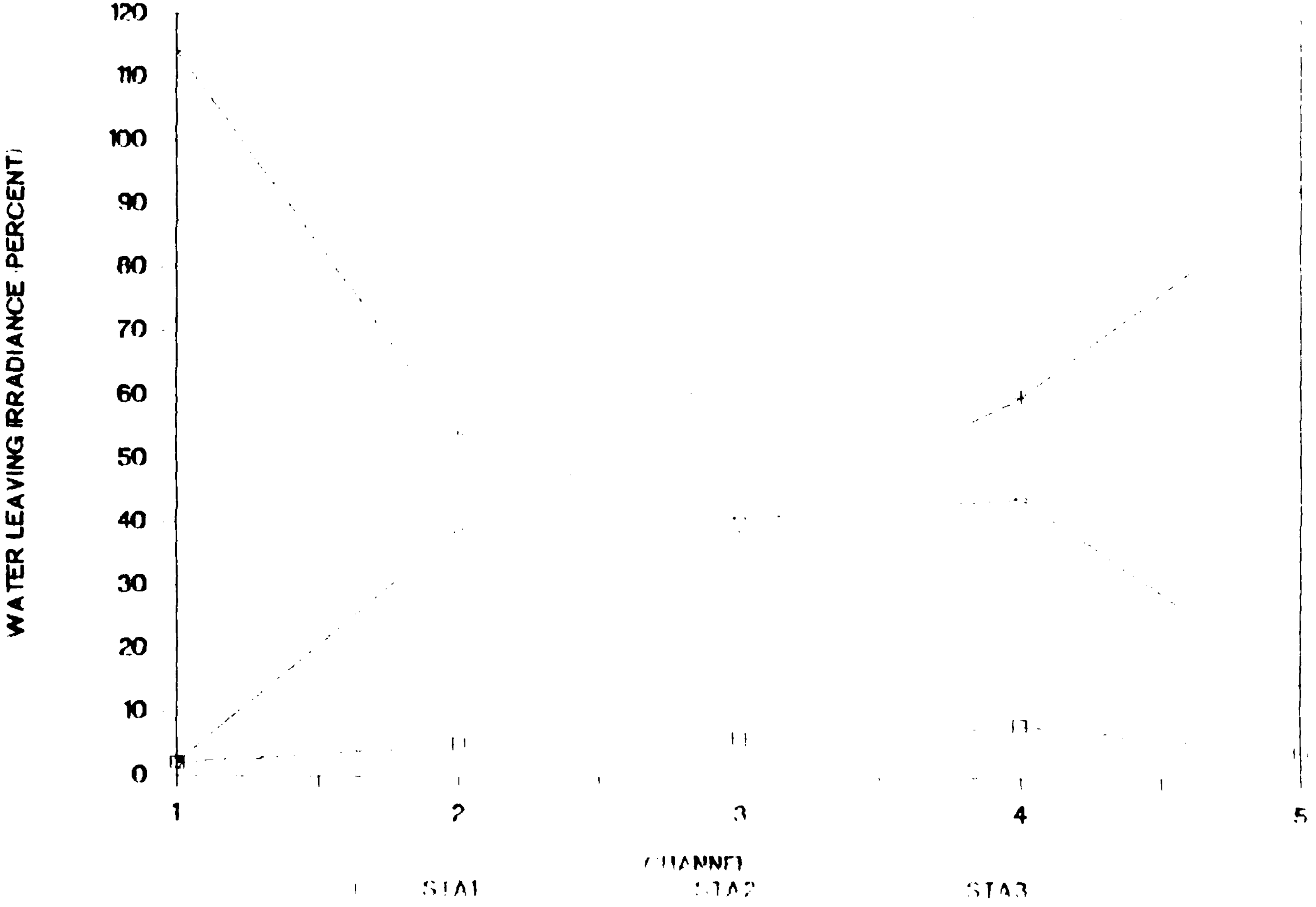


FIG. 3

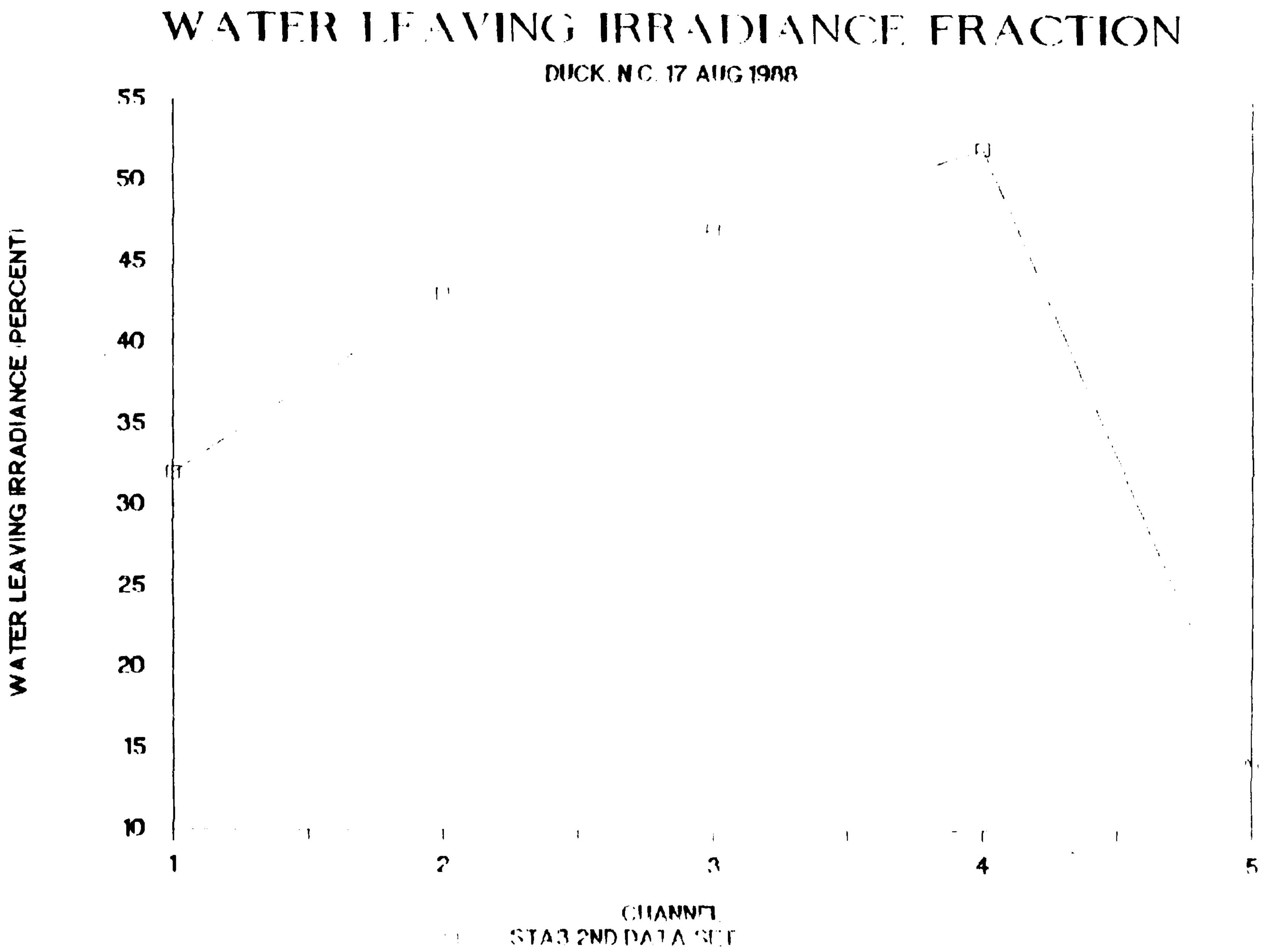

WATER LEAVING IRRADIANCE FRACTION
DUCK, N.C. 17 AUG 1988
WATER LEAVING IRRADIANCE (PERCENT)
55
50
45
40
35
30
25
20
15
10
1
2
3
4
5
CHANNEL
STA3 2ND DATA SET

FIG. 4.

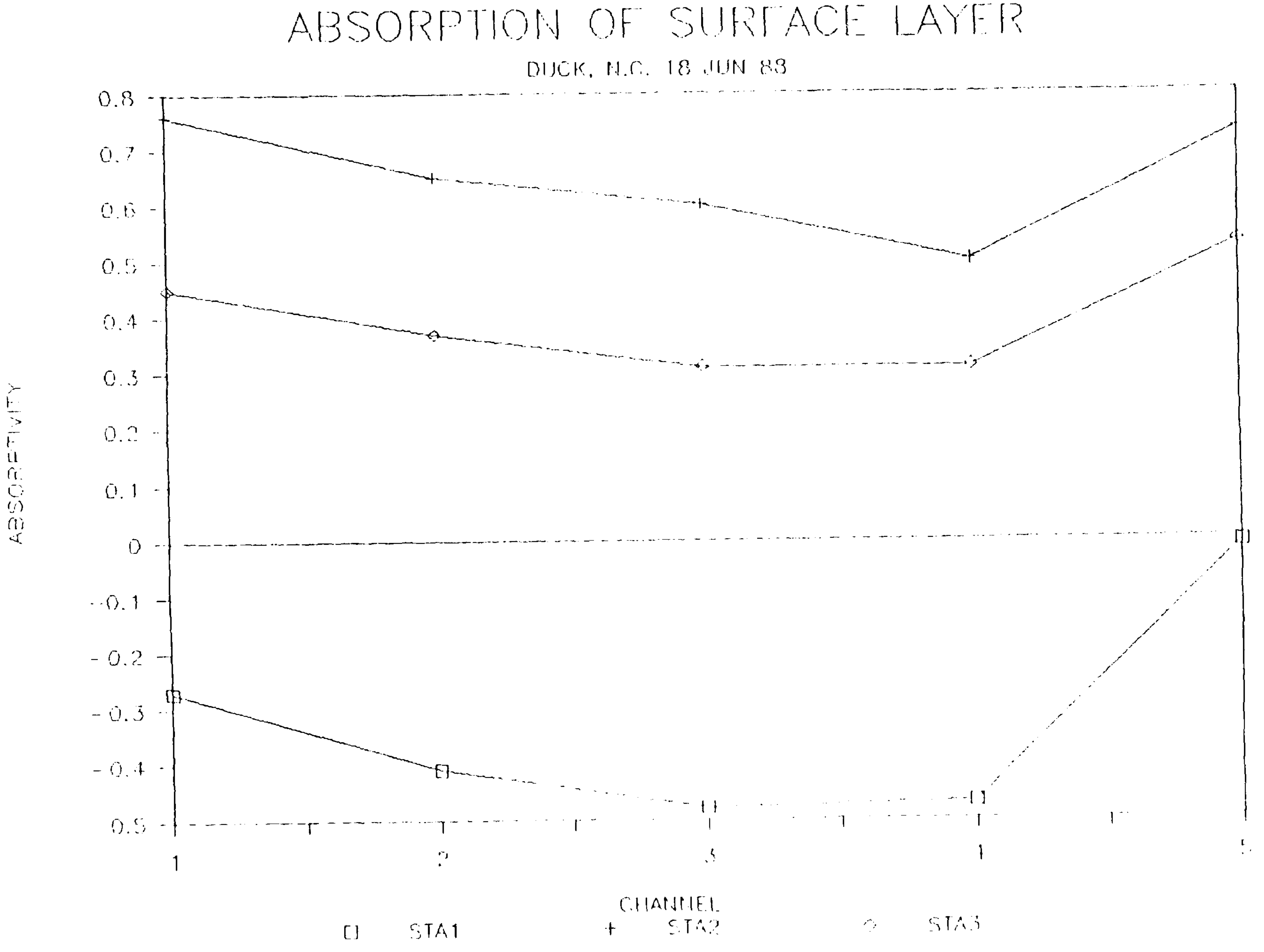

ABSORPTION OF SURFACE LAYER
DUCK, N.C. 18 JUN 83
ABSORPTIVITY
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
1
2
3
4
5
CHANNEL
□ STA1
+ STA2
◇ STA3

FIG. 5

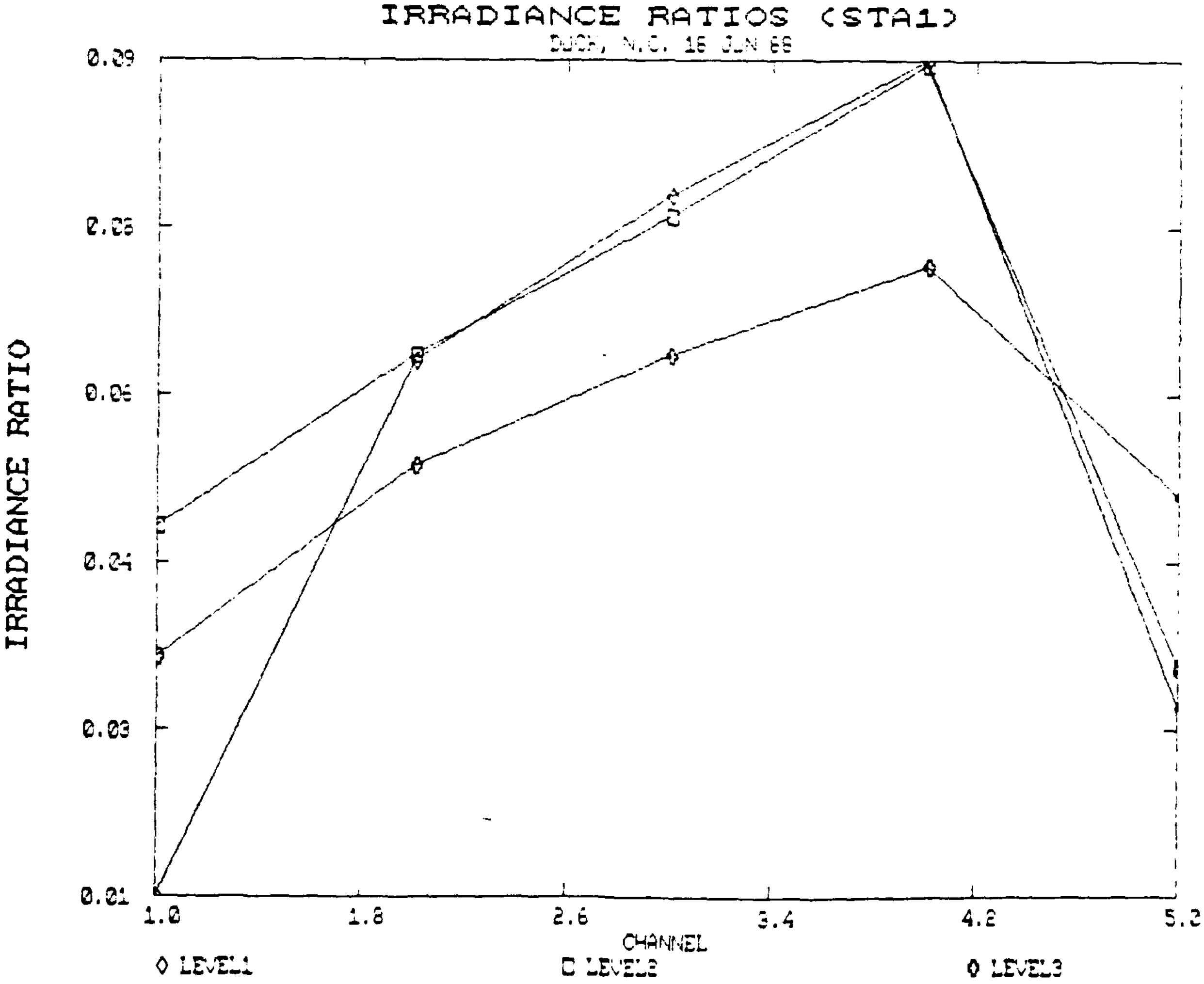

IRRADIANCE RATIOS (STA1)
DUCK, N.C. 16 JUN 88
IRRADIANCE RATIO
0.09
0.08
0.06
0.04
0.03
0.01
1.0
1.8
2.6
3.4
4.2
5.2
CHANNEL
◊ LEVEL1
□ LEVEL2
◊ LEVEL3

FIG. 6.

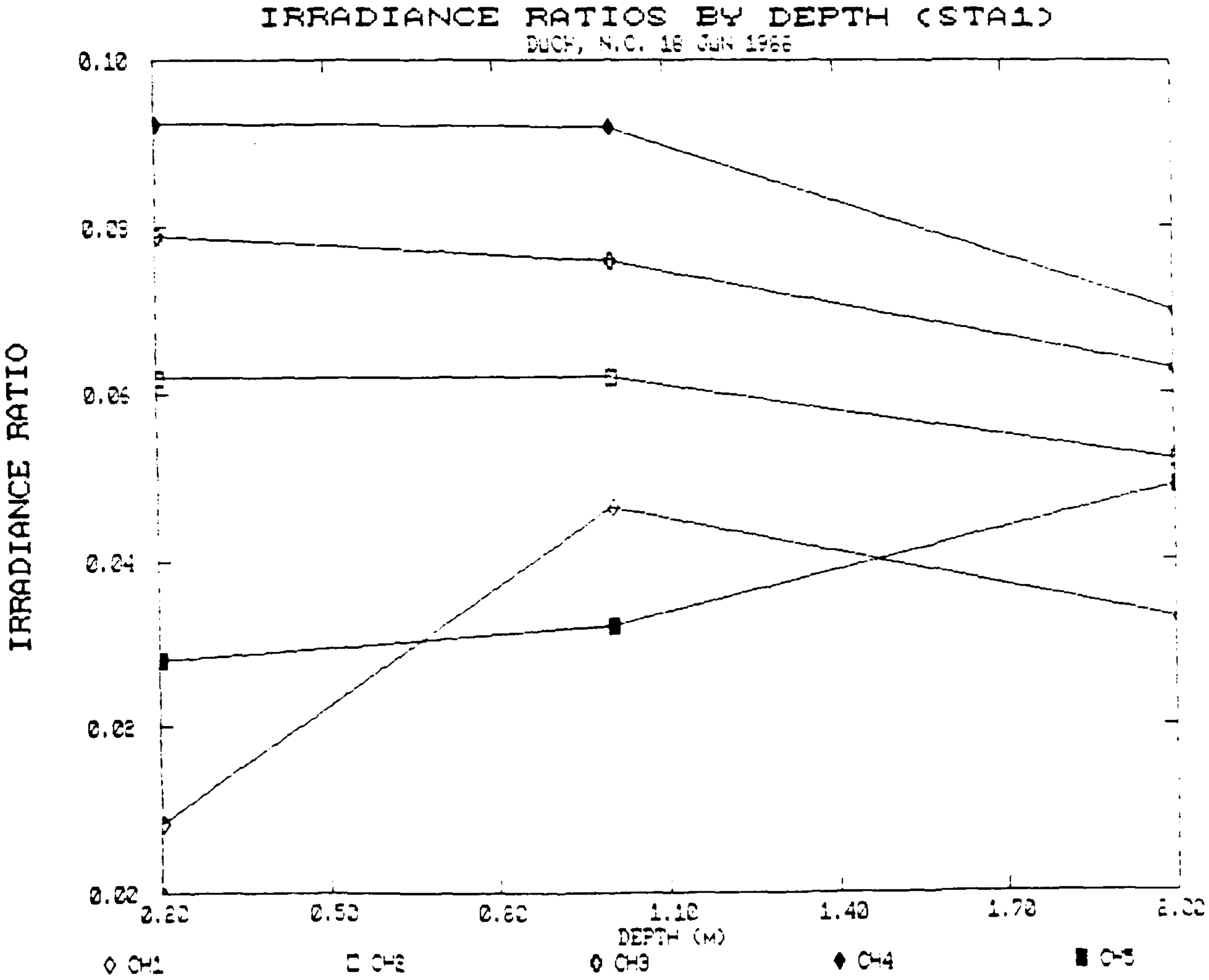
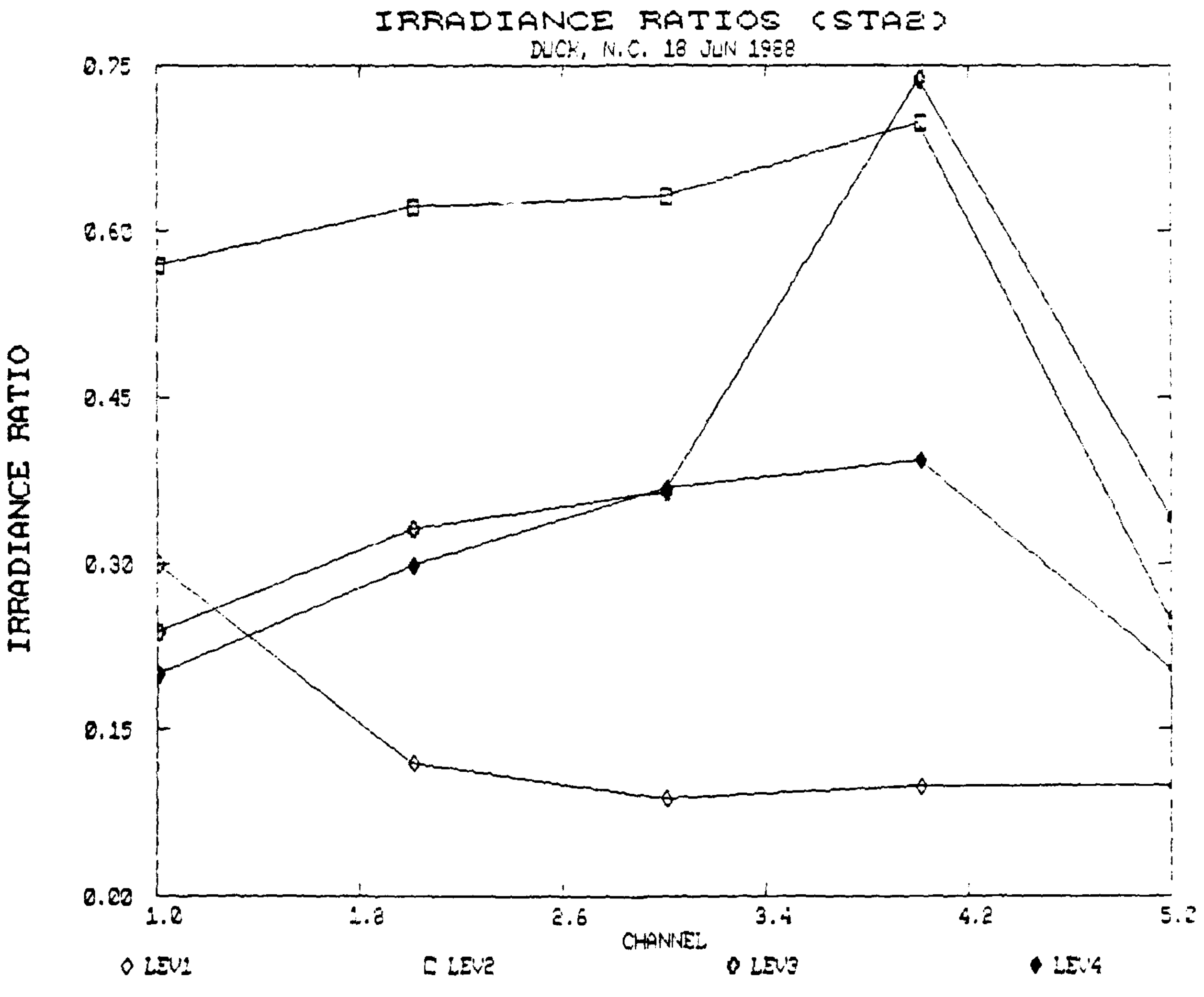

IRRADIANCE RATIOS BY DEPTH (STA1)
DUCK, N.C. 18 JUN 1988
IRRADIANCE RATIO
0.10
0.08
0.06
0.04
0.02
0.00
0.20
0.50
0.80
1.10
1.40
1.70
2.00
DEPTH (M)
◇ CH1
□ CH2
◇ CH3
◆ CH4
■ CH5

FIG. 7.



IRRADIANCE RATIOS (STA2)
DUCK, N.C. 18 JUN 1988
IRRADIANCE RATIO
0.75
0.60
0.45
0.30
0.15
0.00
1.0
1.8
2.6
3.4
4.2
5.2
CHANNEL
◇ LEV1
□ LEV2
◇ LEV3
◆ LEV4

FIG. 8.

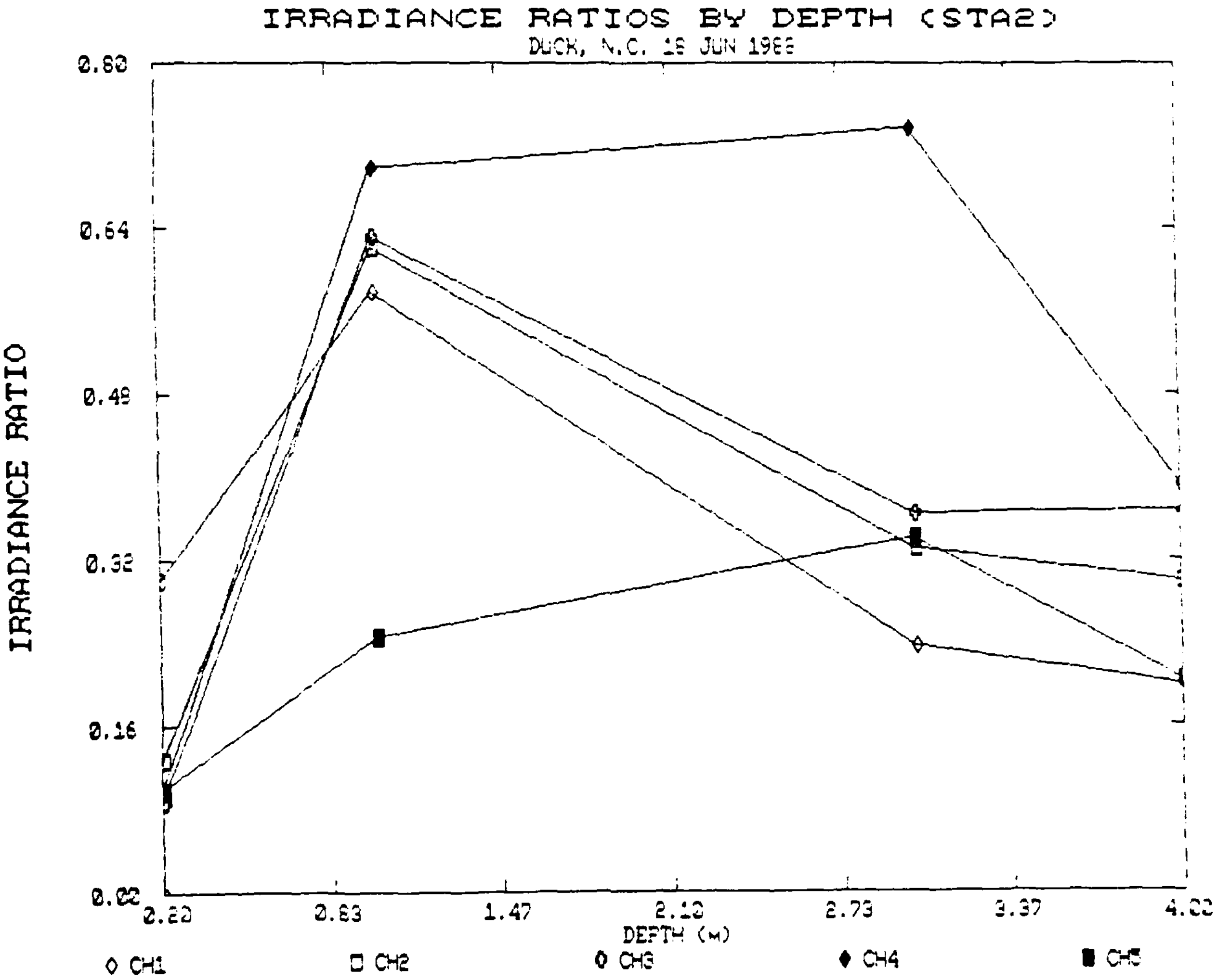

IRRADIANCE RATIOS BY DEPTH (STA2)
DUCK, N.C. 18 JUN 1988
IRRADIANCE RATIO
0.80
0.64
0.48
0.32
0.16
0.00
0.20
0.83
1.47
2.10
2.73
3.37
4.00
DEPTH (M)
◇ CH1
□ CH2
○ CH3
◆ CH4
■ CH5

FIG. 9.

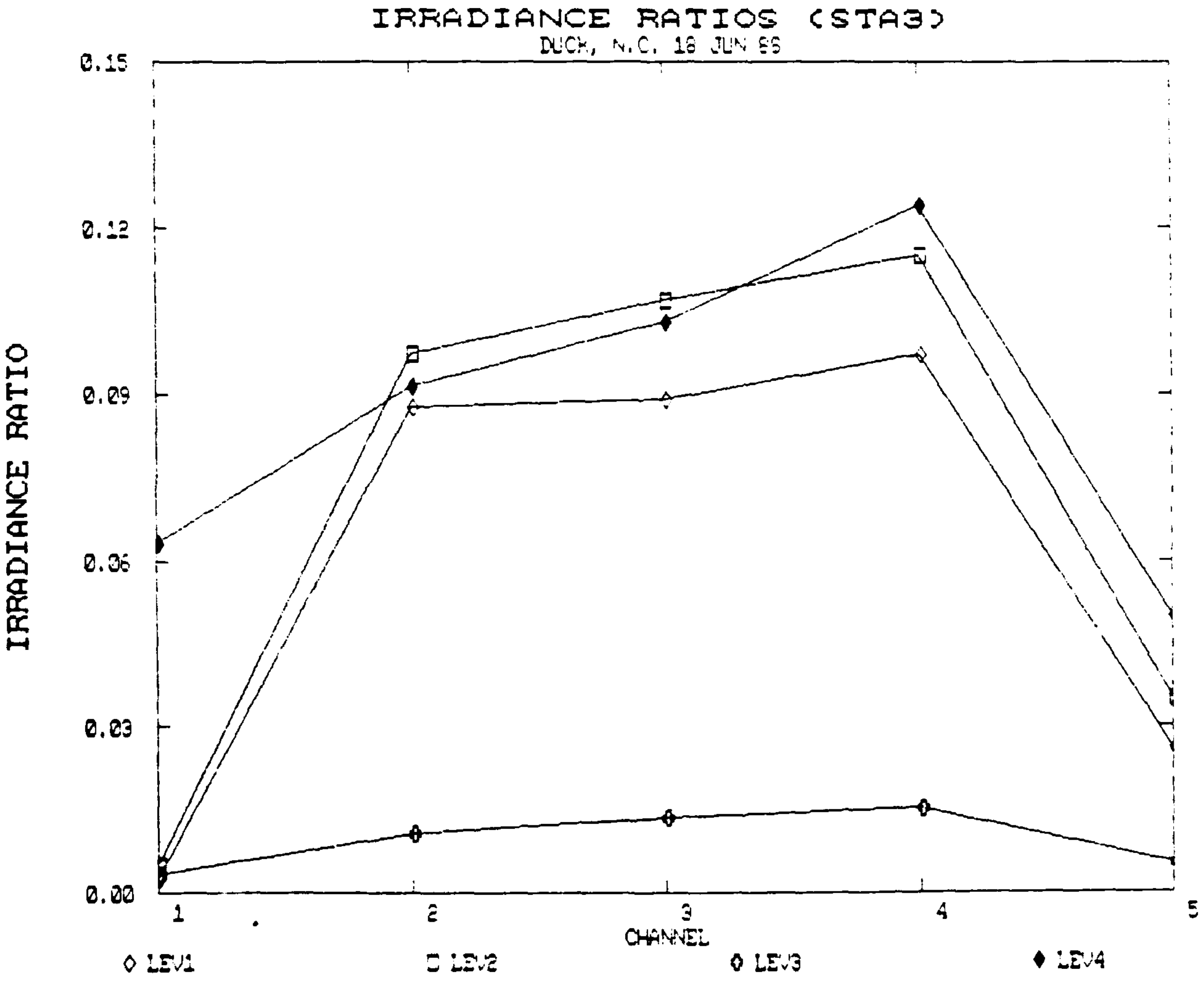

IRRADIANCE RATIOS (STA3)
DUCK, N.C. 18 JUN 86
IRRADIANCE RATIO
0.15
0.12
0.09
0.06
0.03
0.00
1
2
3
4
5
CHANNEL
◇ LEV1
□ LEV2
◇ LEV3
◆ LEV4

FIG. 10.

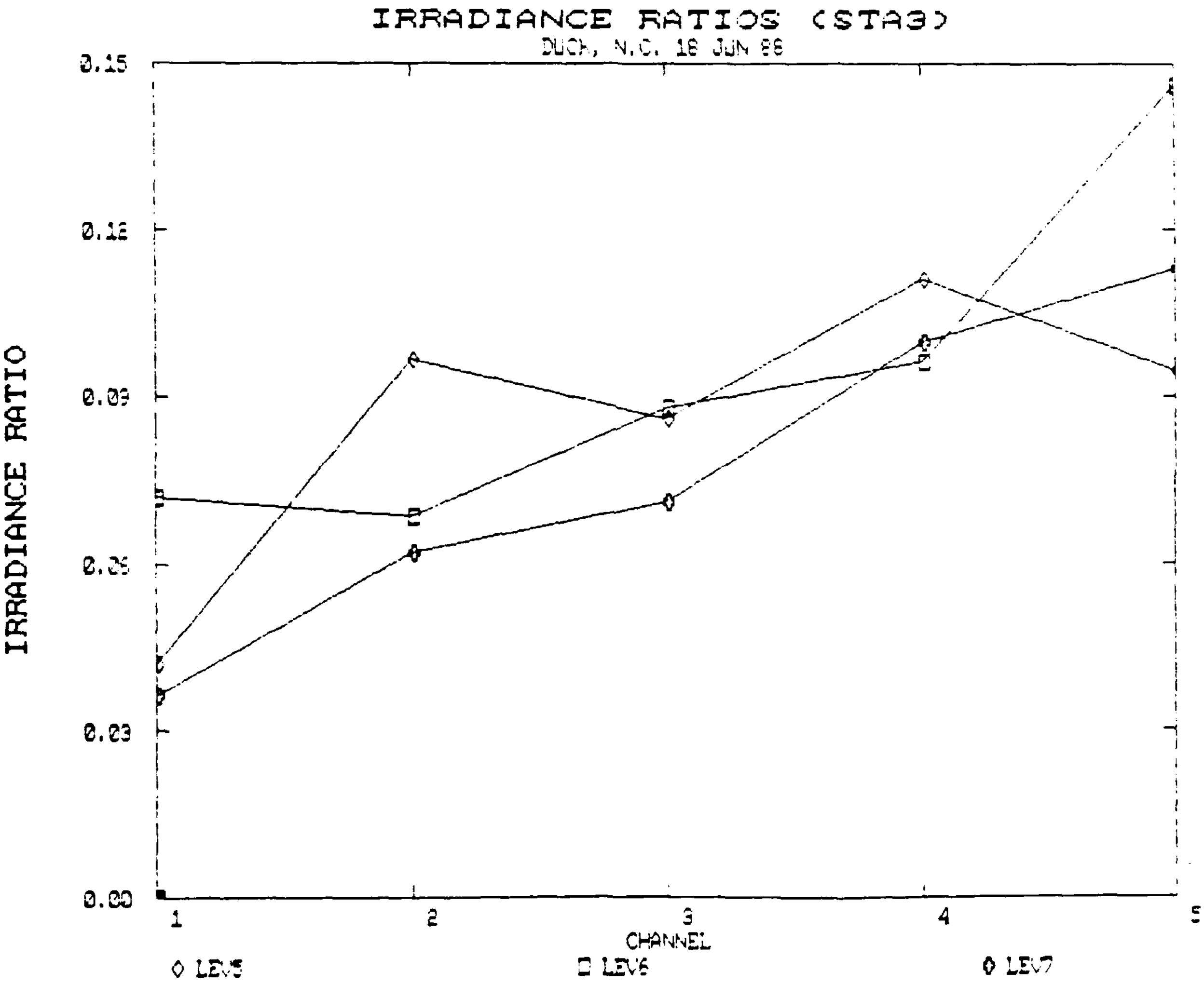

IRRADIANCE RATIOS (STA3)
DUCK, N.C. 18 JUN 88
IRRADIANCE RATIO
0.15
0.12
0.09
0.06
0.03
0.00
1
2
3
4
5
CHANNEL
◇ LEV5
□ LEV6
◇ LEV7

FIG. 11.

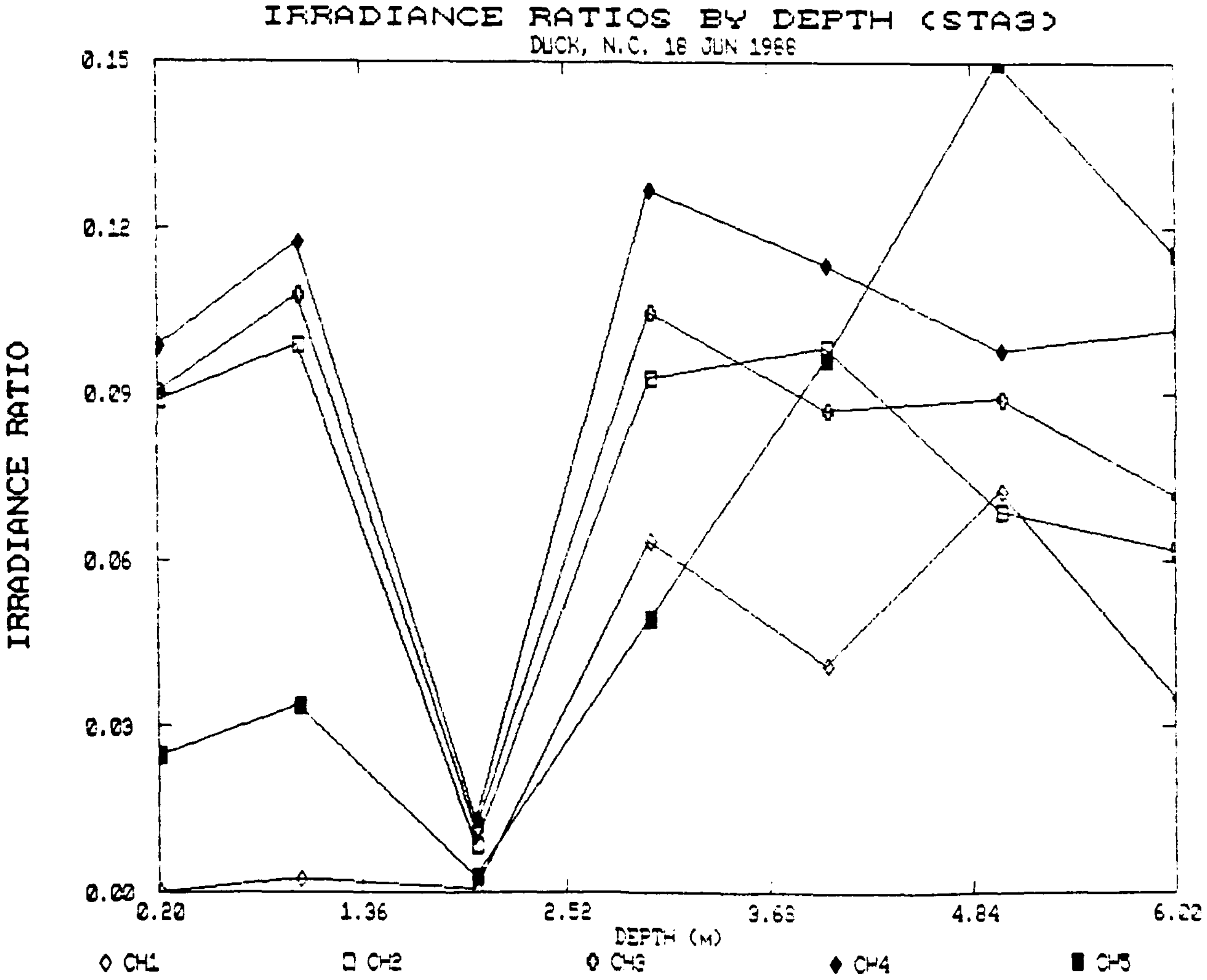
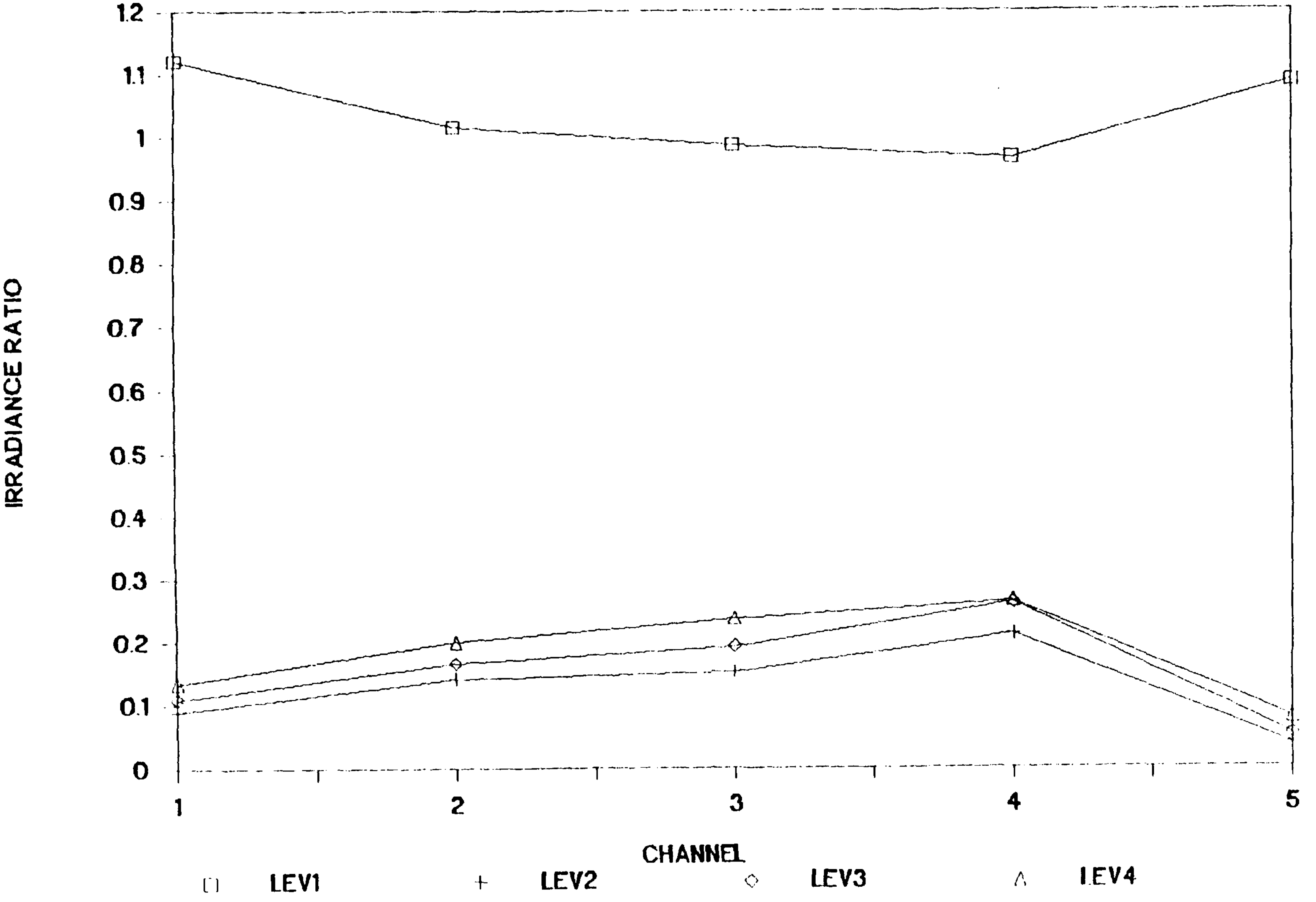

IRRADIANCE RATIOS BY DEPTH (STA3)
DUCK, N.C. 18 JUN 1988
IRRADIANCE RATIO
0.15
0.12
0.09
0.06
0.03
0.00
0.20
1.36
2.52
3.68
4.84
6.22
DEPTH (M)
◇ CH1
□ CH2
○ CH3
◆ CH4
■ CH5

FIG. 12.



IRRADIANCE RATIOS (STA2)

DUCK, N.C. 17 AUG 1988

FIG. 13

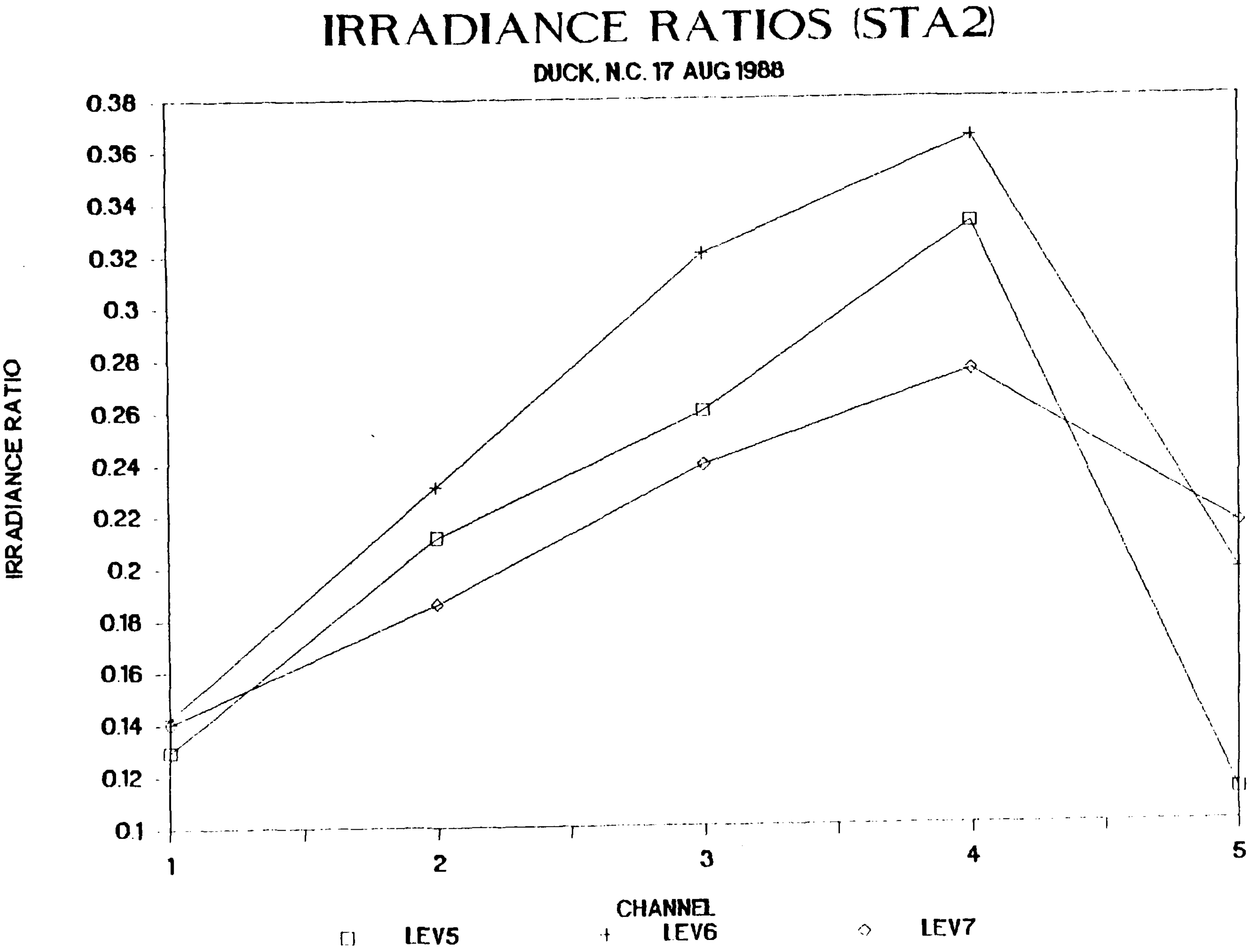

IRRADIANCE RATIOS (STA2)
DUCK, N.C. 17 AUG 1988
IRRADIANCE RATIO
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
1
2
3
4
5
CHANNEL
□ LEV5
+ LEV6
◇ LEV7

FIG. 14.

IRRADIANCE RATIOS BY DEPTH (STA2)

DUCK, N.C. 17 AUG 1988

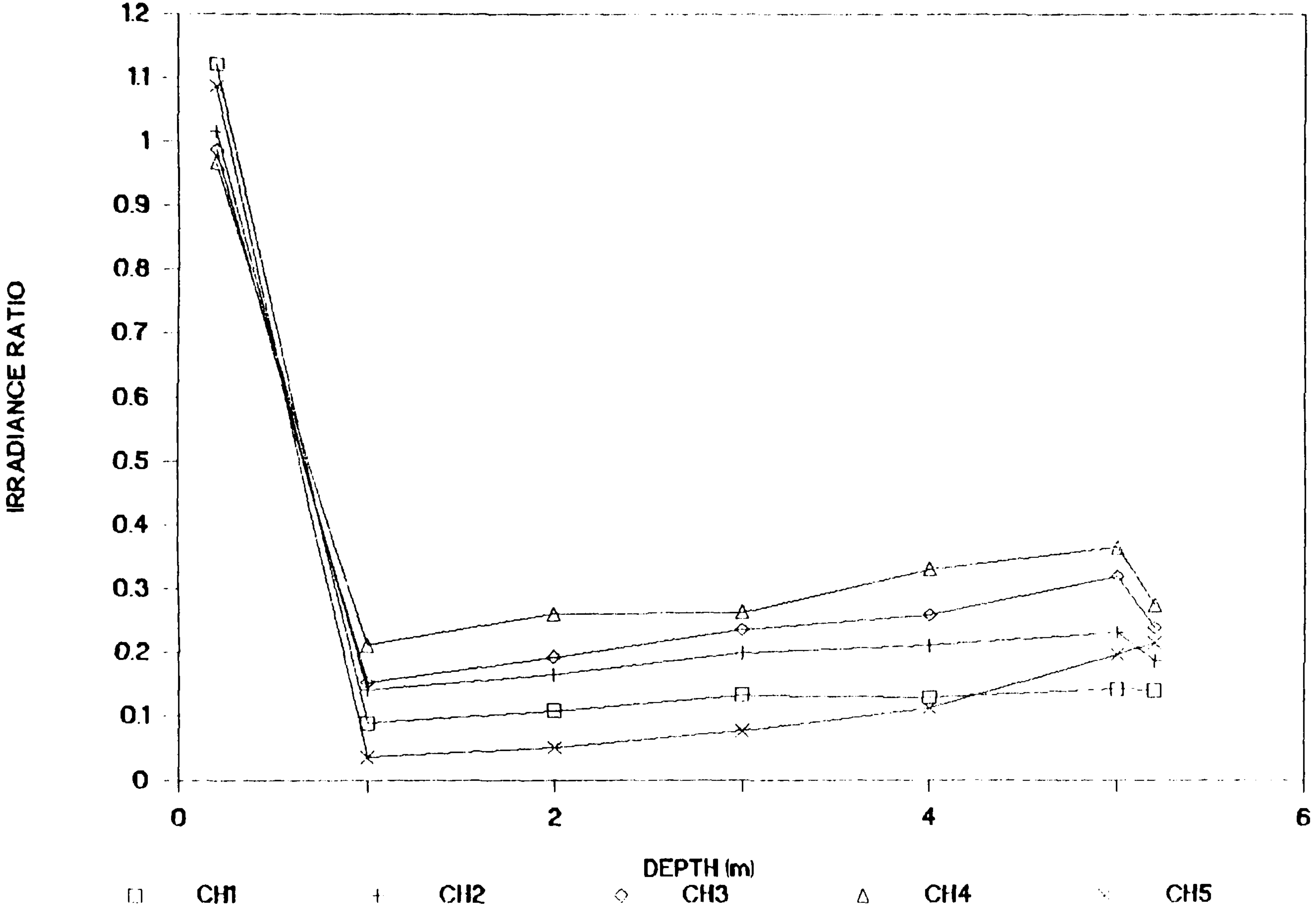


FIG. 15

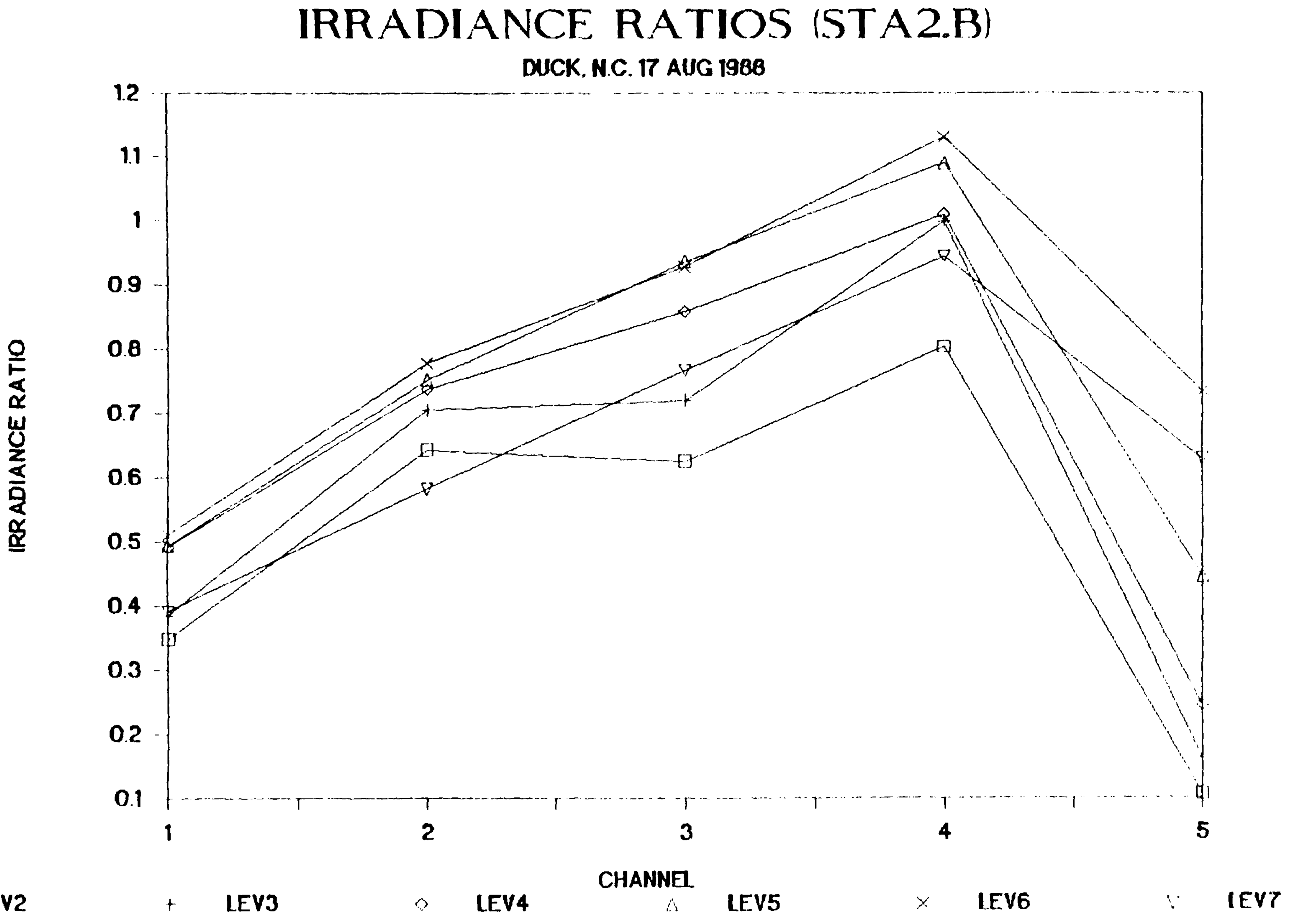

IRRADIANCE RATIOS (STA2.B)
DUCK, N.C. 17 AUG 1988
IRRADIANCE RATIO
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
CHANNEL
V2
+ LEV3
◇ LEV4
△ LEV5
× LEV6
▽ LEV7

FIG 16

IRRADIANCE RATIOS BY DEPTH (STA2.B)

DUCK, N.C. 17 AUG 1988

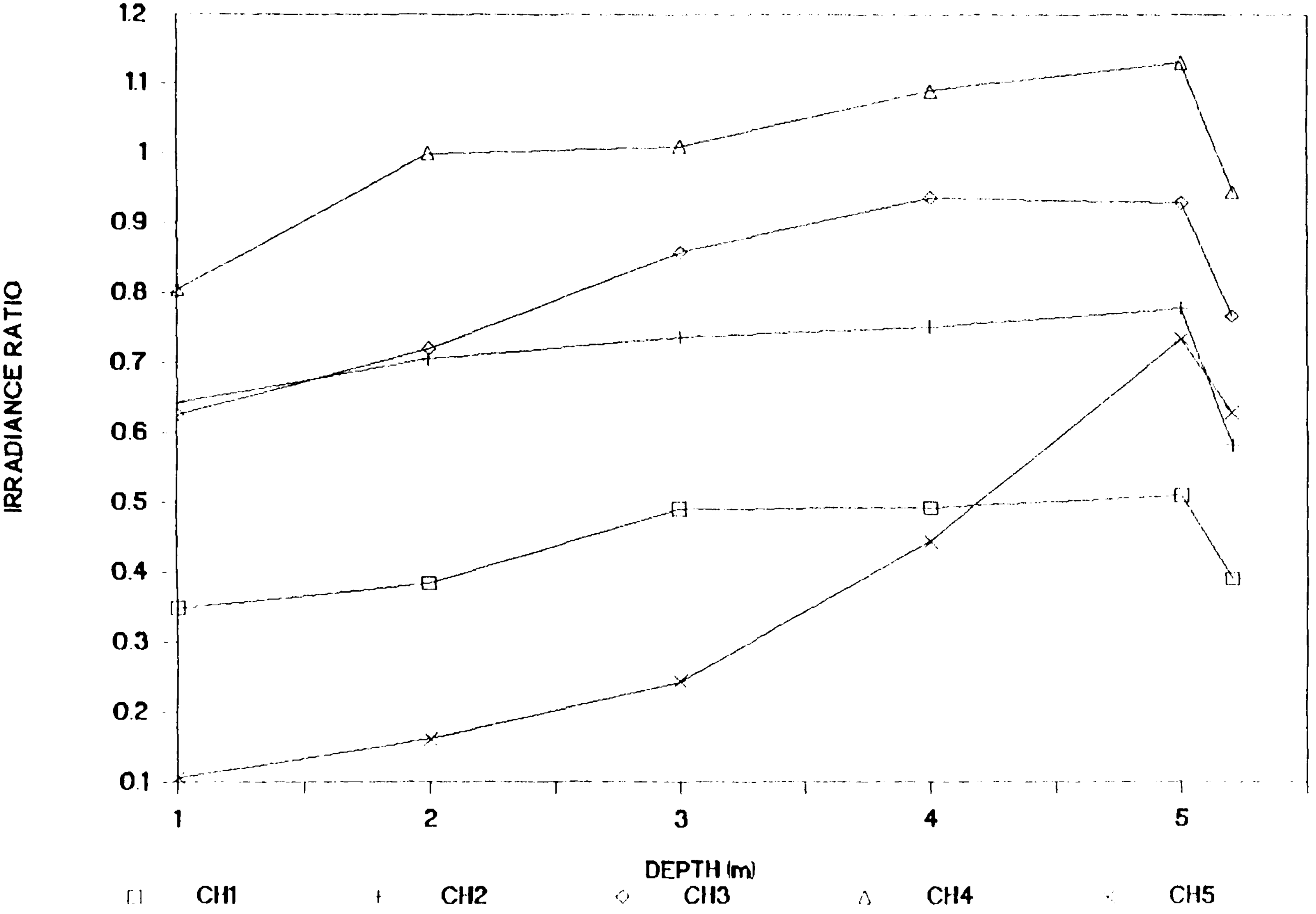


FIG. 17

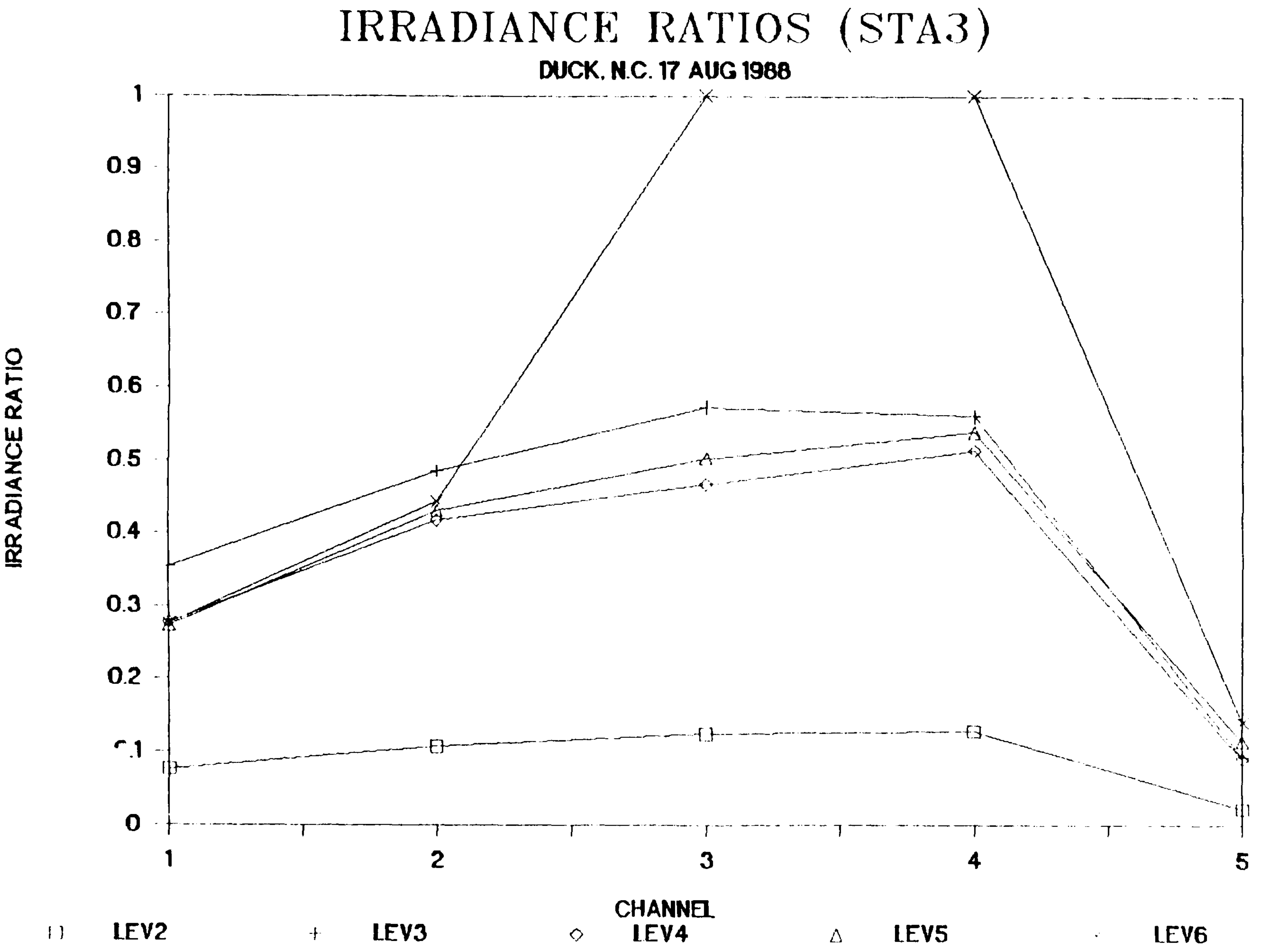

IRRADIANCE RATIOS (STA3)
DUCK, N.C. 17 AUG 1988
IRRADIANCE RATIO
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
.1
0
1
2
3
4
5
CHANNEL
□ LEV2
+ LEV3
◇ LEV4
△ LEV5
· LEV6

FIG. 18

IRRADIANCE RATIOS BY DEPTH (STA3)

DUCK, N.C. 17 AUG 1988

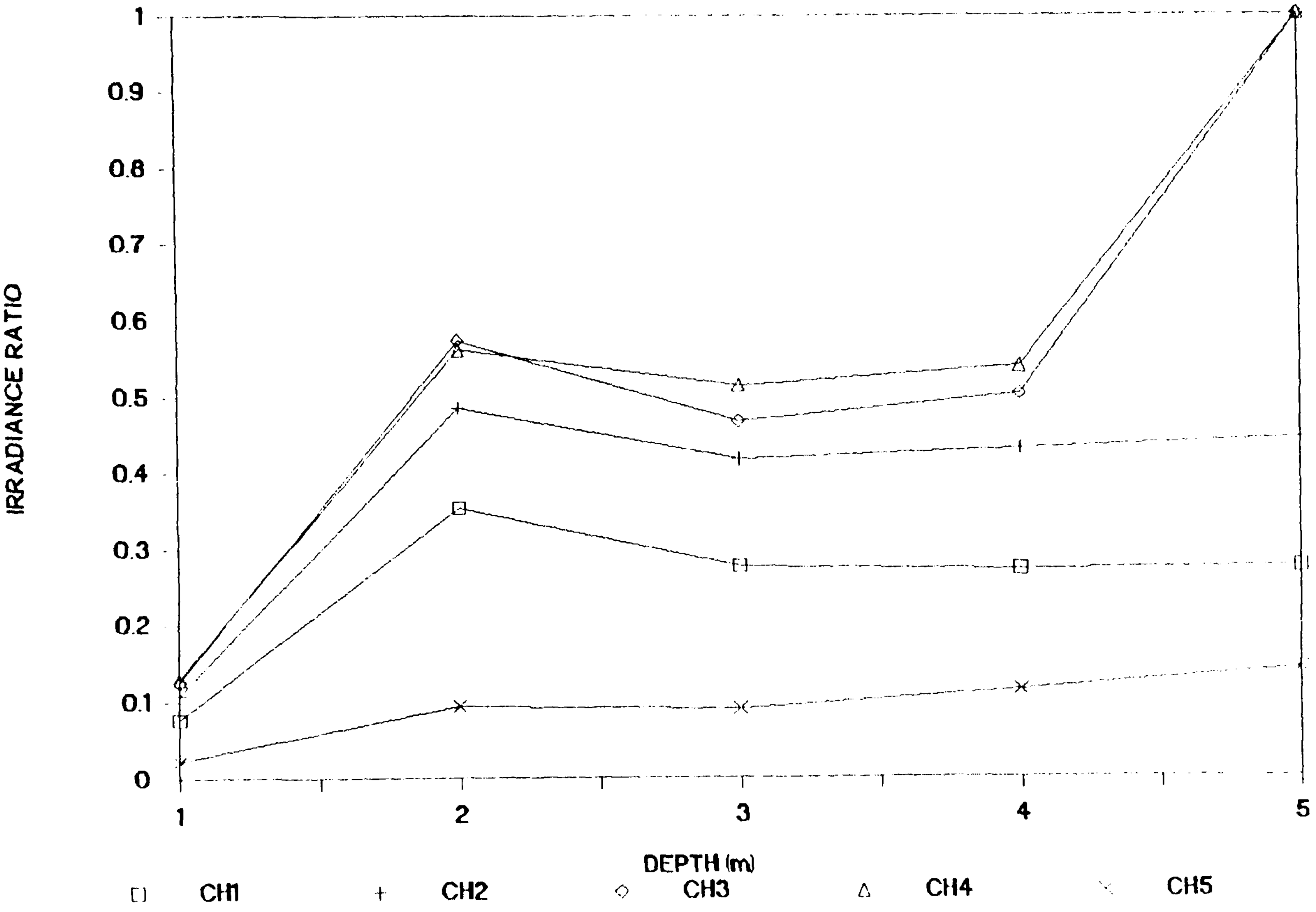


FIG. 20.

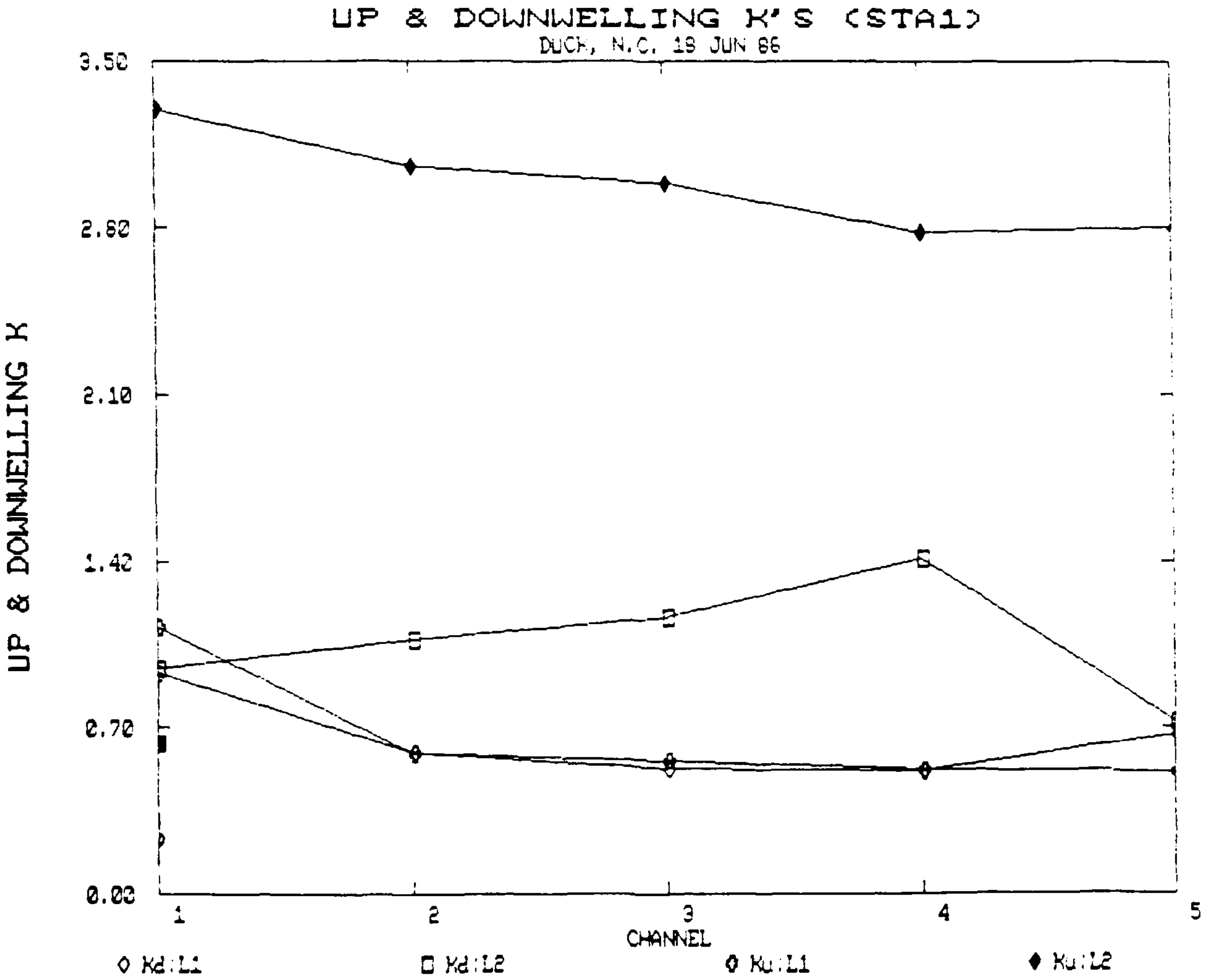
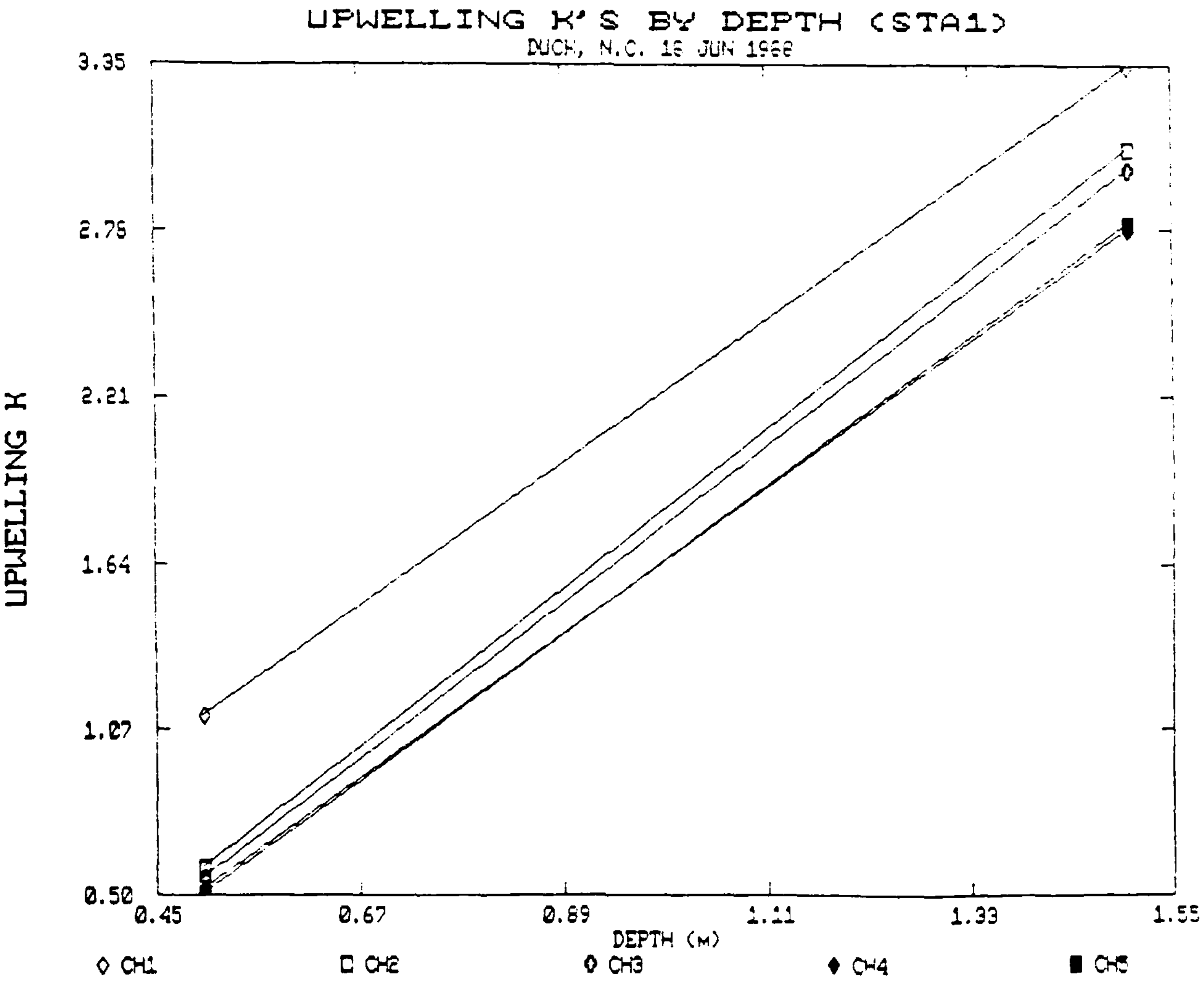

UP & DOWNWELLING K'S (STA1)
DUCK, N.C. 18 JUN 86
UP & DOWNWELLING K
3.50
2.80
2.10
1.40
0.70
0.00
1
2
3
4
5
CHANNEL
◇ Kd:L1
□ Kd:L2
◇ Ku:L1
◆ Ku:L2

FIG. 21.



UPWELLING K'S BY DEPTH (STA1)
DUCK, N.C. 16 JUN 1988
UPWELLING K
3.35
2.78
2.21
1.64
1.07
0.50
0.45
0.67
0.89
1.11
1.33
1.55
DEPTH (M)
◇ CH1
□ CH2
○ CH3
◆ CH4
■ CH5

FIG. 22.

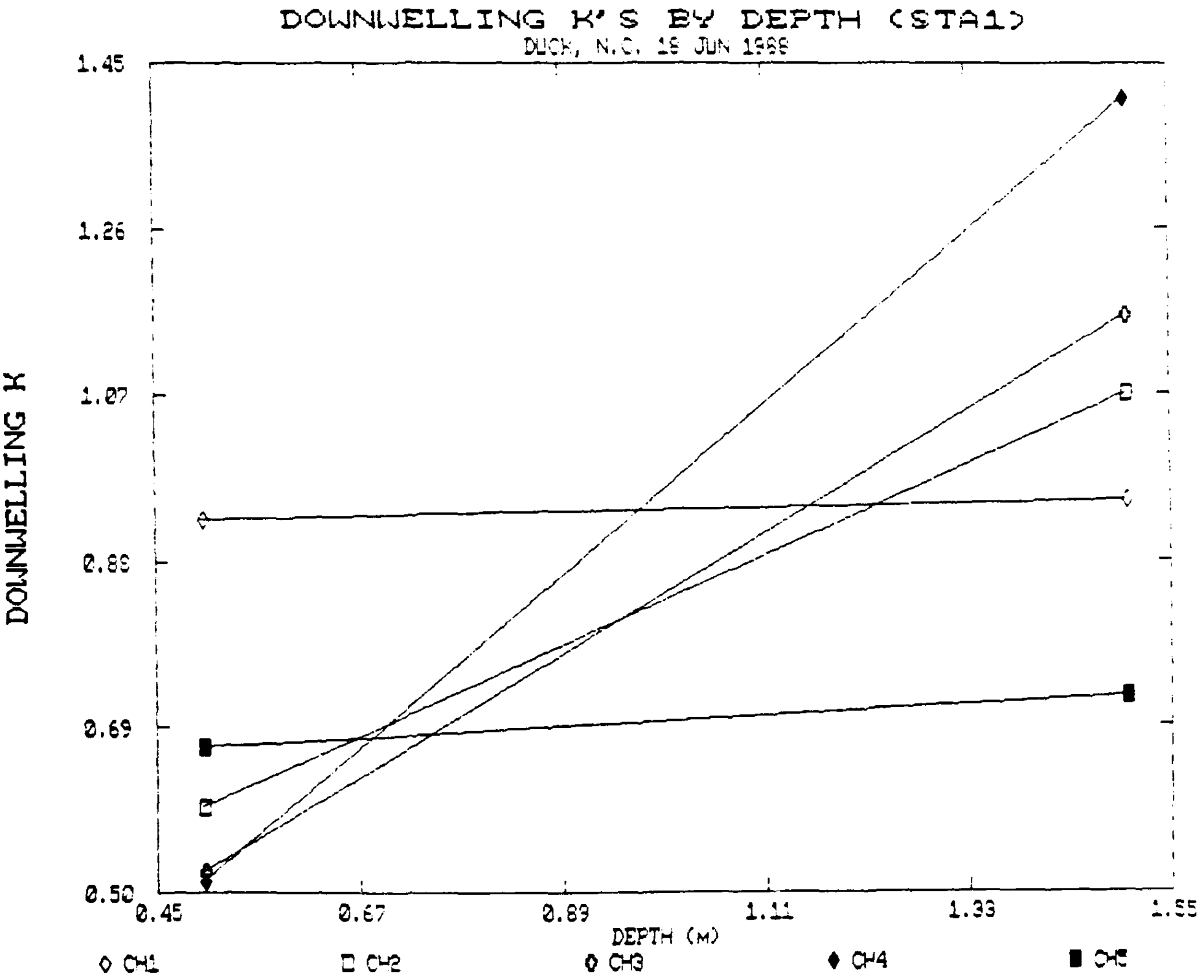

DOWNWELLING K'S BY DEPTH (STA1)
DUCK, N.C. 19 JUN 1988
DOWNWELLING K
1.45
1.26
1.07
0.88
0.69
0.50
0.45
0.67
0.89
1.11
1.33
1.55
DEPTH (M)
◇ CH1
□ CH2
◇ CH3
◆ CH4
■ CH5

FIG. 23.

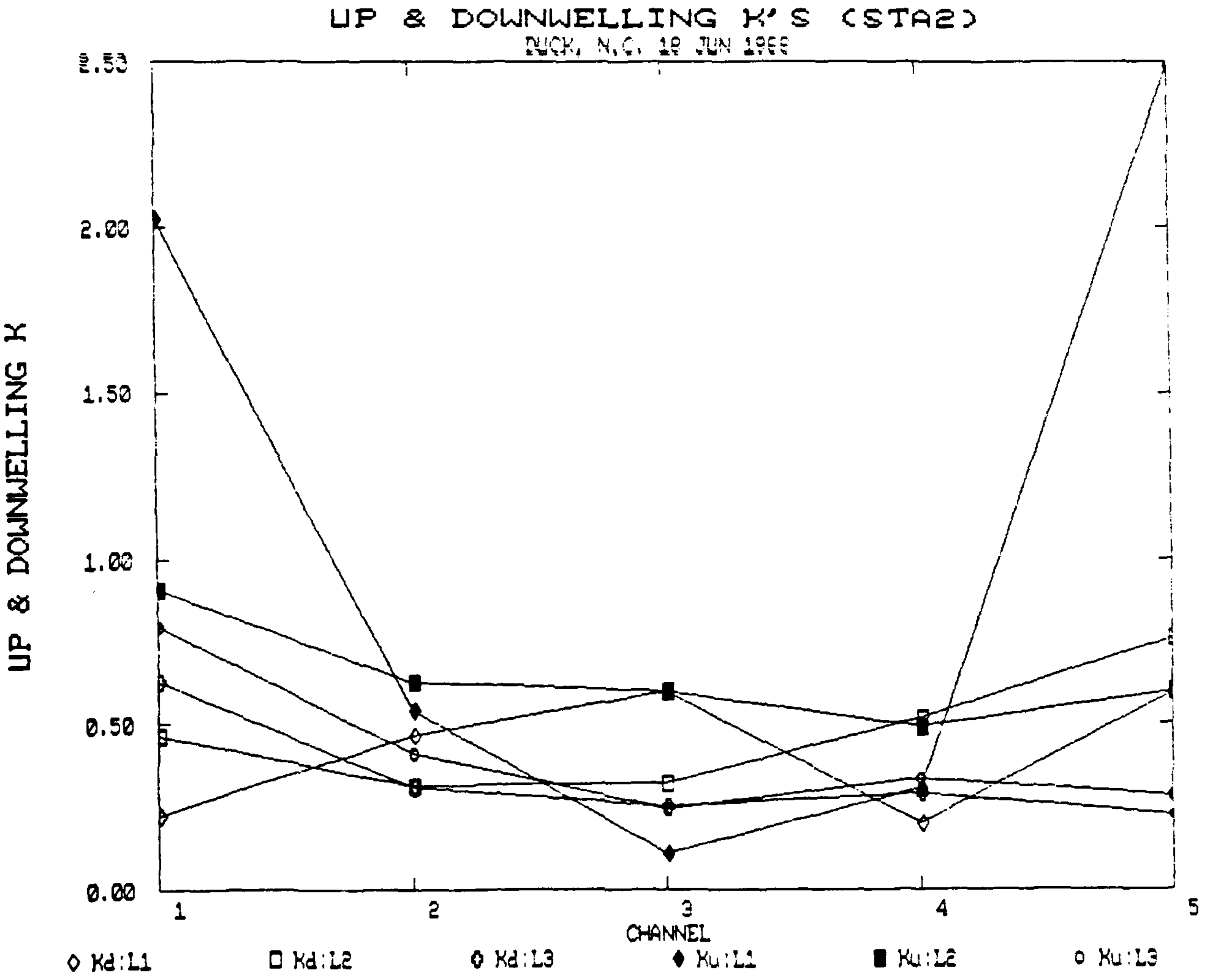

UP & DOWNWELLING K'S (STA2)
DUCK, N.C. 10 JUN 1988
2.50
2.00
1.50
1.00
0.50
0.00
UP & DOWNWELLING K
1
2
3
4
5
CHANNEL
◇ Kd:L1
☐ Kd:L2
◇ Kd:L3
◆ Ku:L1
■ Ku:L2
○ Ku:L3

FIG. 24.

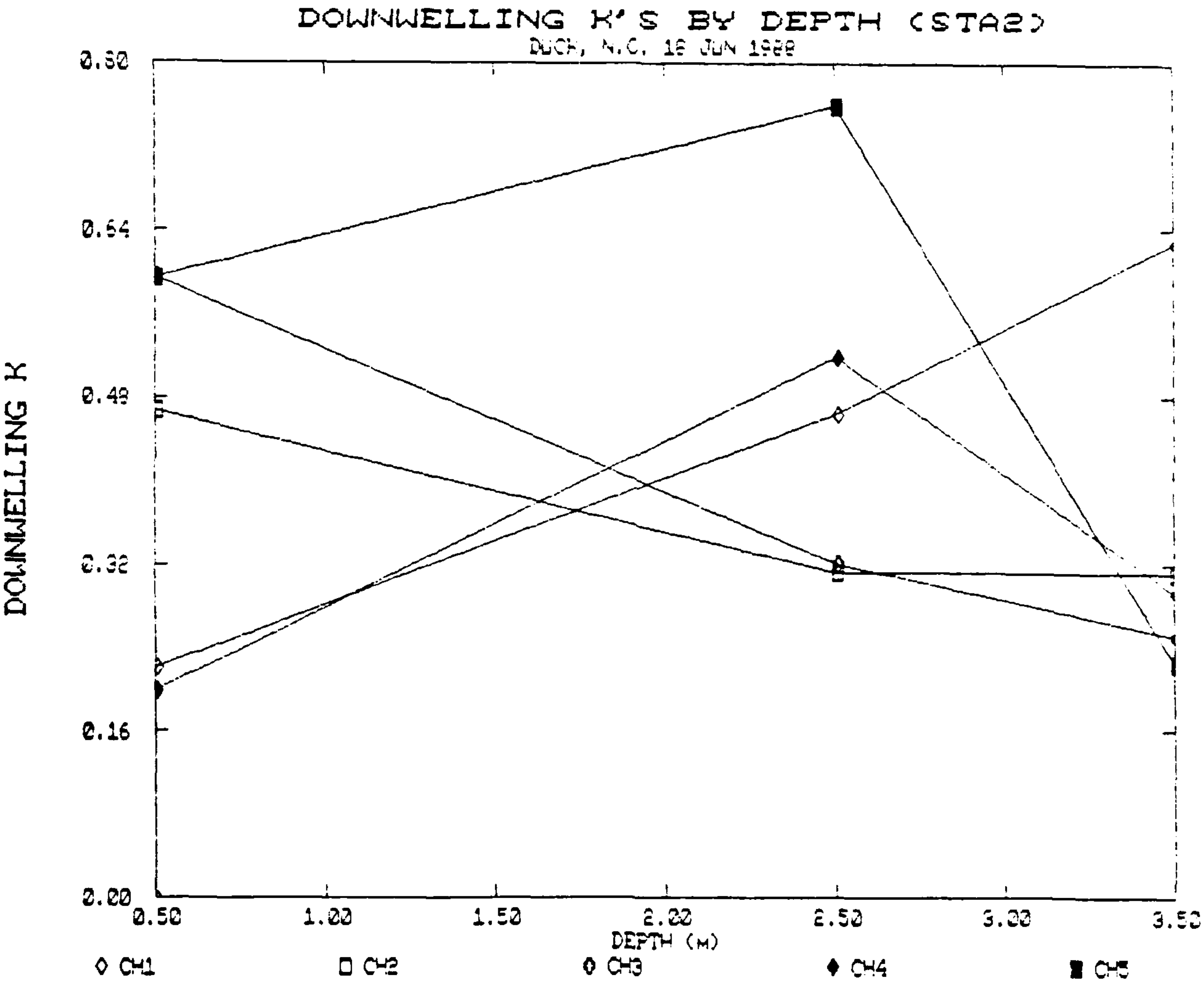

DOWNWELLING K'S BY DEPTH (STA2)
DUCK, N.C. 18 JUN 1988
DOWNWELLING K
0.80
0.64
0.48
0.32
0.16
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
DEPTH (M)
◇ CH1
□ CH2
○ CH3
♦ CH4
■ CH5

FIG. 25.

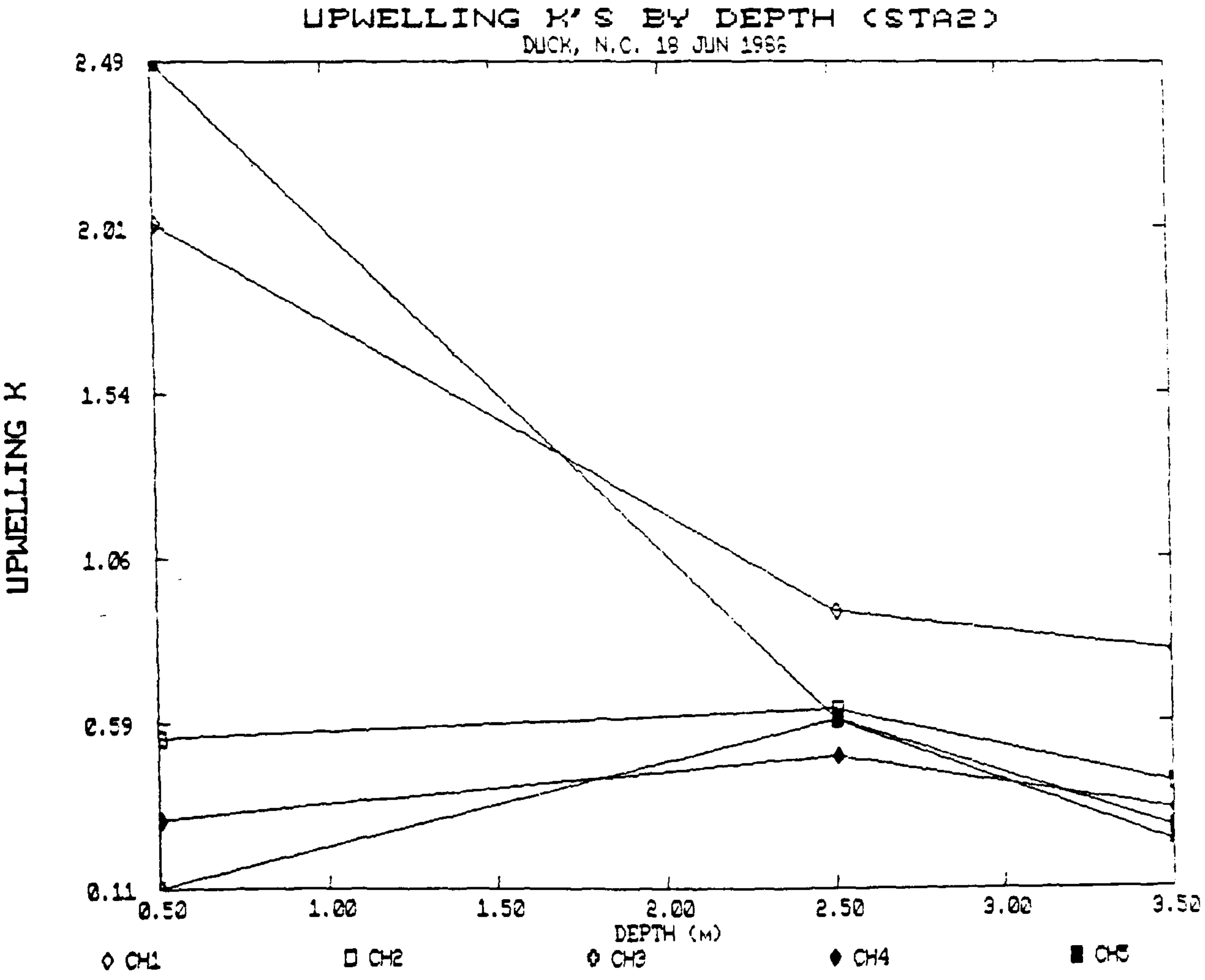

UPWELLING K'S BY DEPTH (STA2)
DUCK, N.C. 18 JUN 1986
UPWELLING K
2.49
2.01
1.54
1.06
0.59
0.11
0.50
1.00
1.50
2.00
2.50
3.00
3.50
DEPTH (M)
◊ CH1
□ CH2
◊ CH3
♦ CH4
■ CH5

FIG. 26.

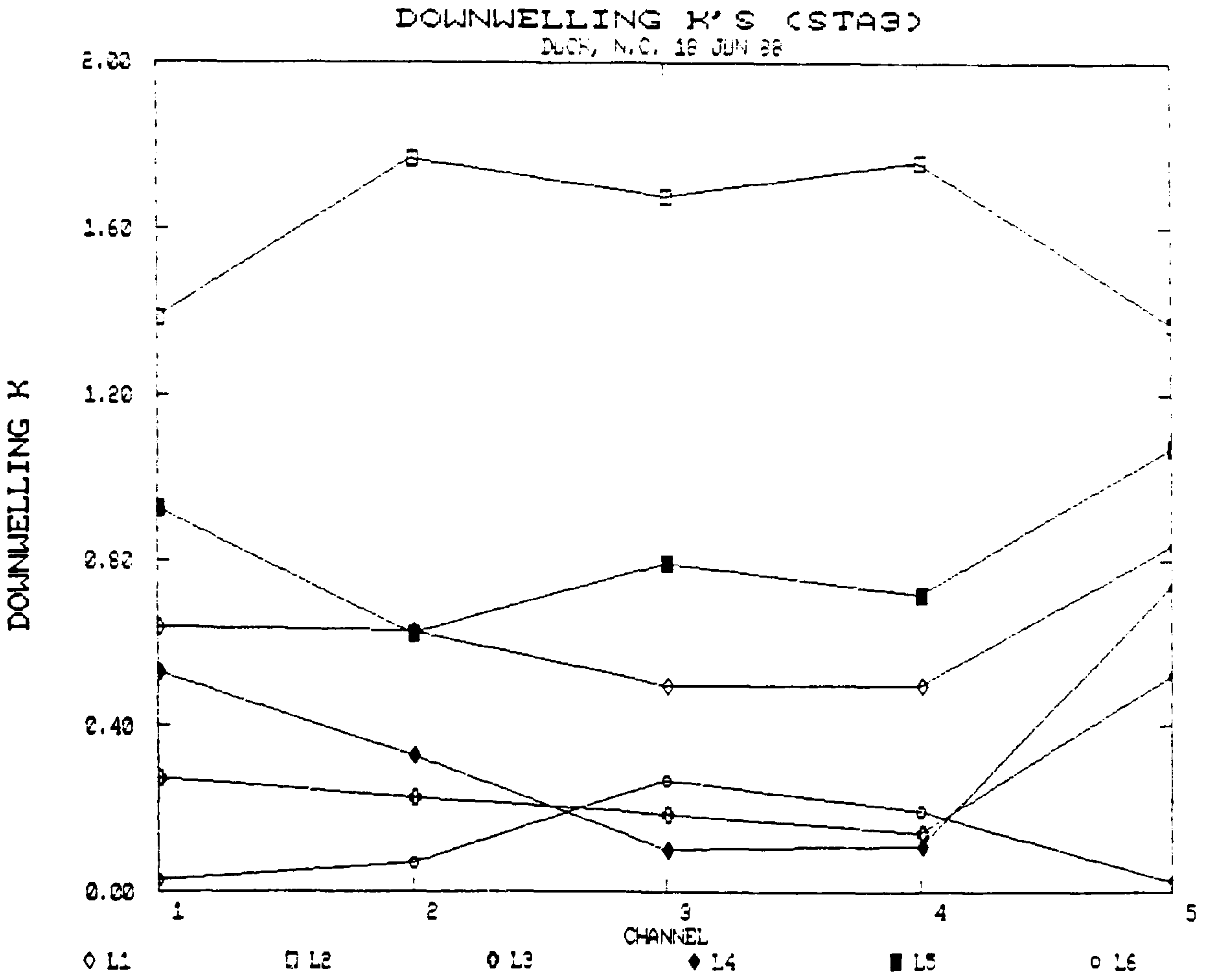
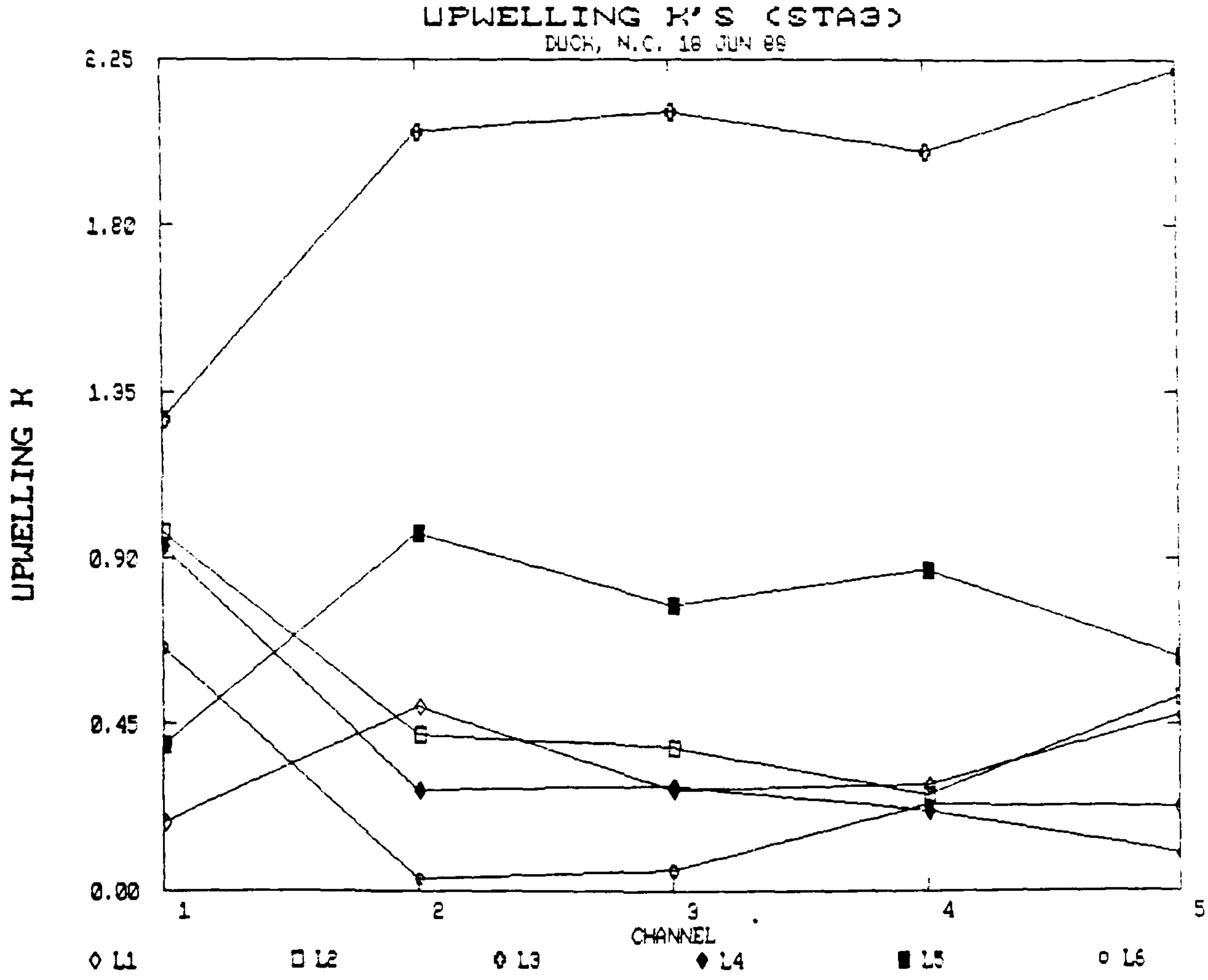
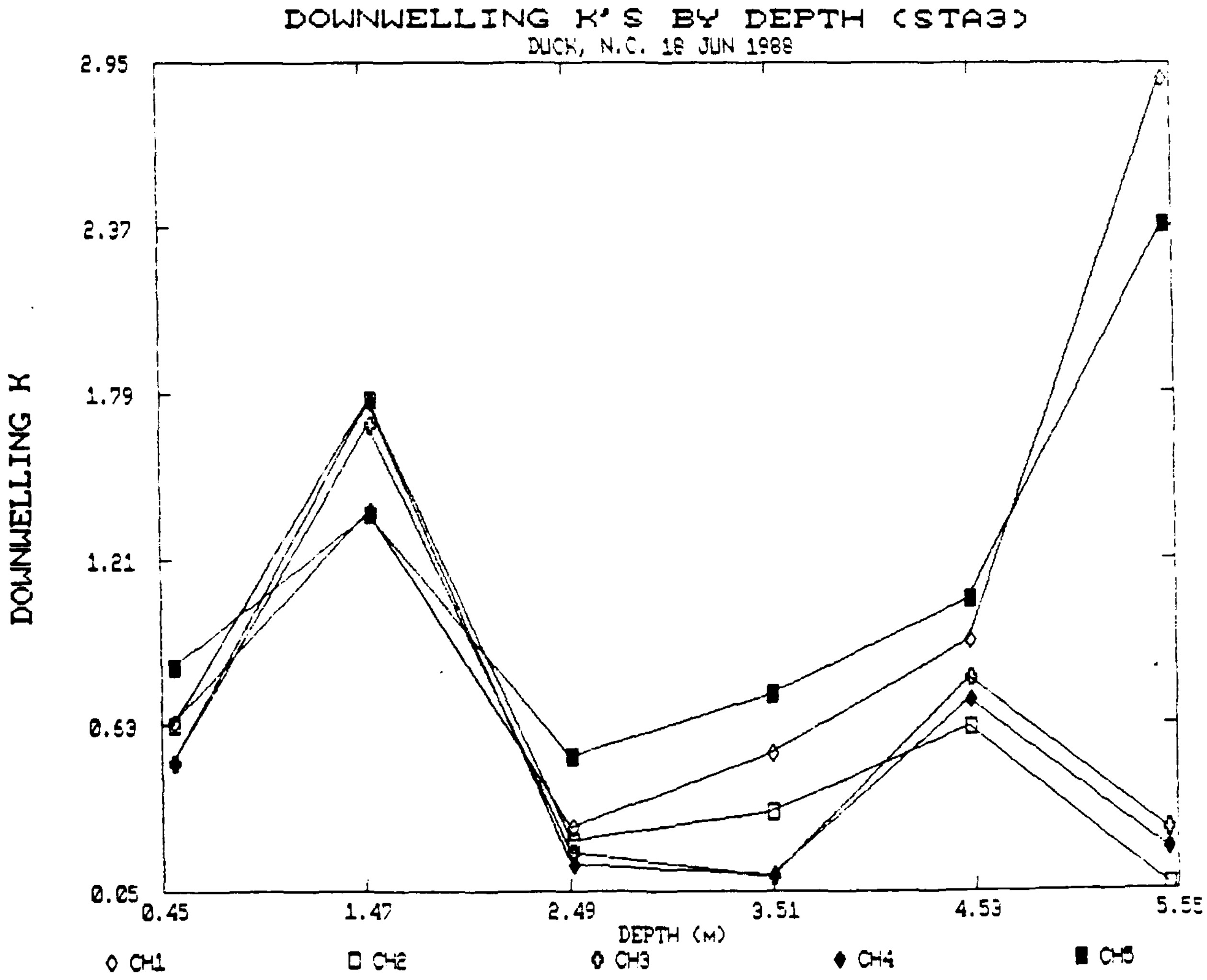

DOWNWELLING K'S (STA3)
DUCK, N.C. 18 JUN 88
DOWNWELLING K
2.00
1.60
1.20
0.80
0.40
0.00
1
2
3
4
5
CHANNEL
◊ L1
□ L2
○ L3
♦ L4
■ L5
○ L6

FIG. 27.



UPWELLING K'S (STA3)
DUCK, N.C. 18 JUN 89
UPWELLING K
2.25
1.80
1.35
0.92
0.45
0.00
1
2
3
4
5
CHANNEL
◇ L1
□ L2
○ L3
◆ L4
■ L5
○ L6

FIG. 28.



DOWNWELLING K'S BY DEPTH (STA3)
DUCK, N.C. 18 JUN 1988
DOWNWELLING K
2.95
2.37
1.79
1.21
0.63
0.05
0.45
1.47
2.49
3.51
4.53
5.55
DEPTH (M)
◇ CH1
□ CH2
◇ CH3
◆ CH4
■ CH5

FIG. 29.

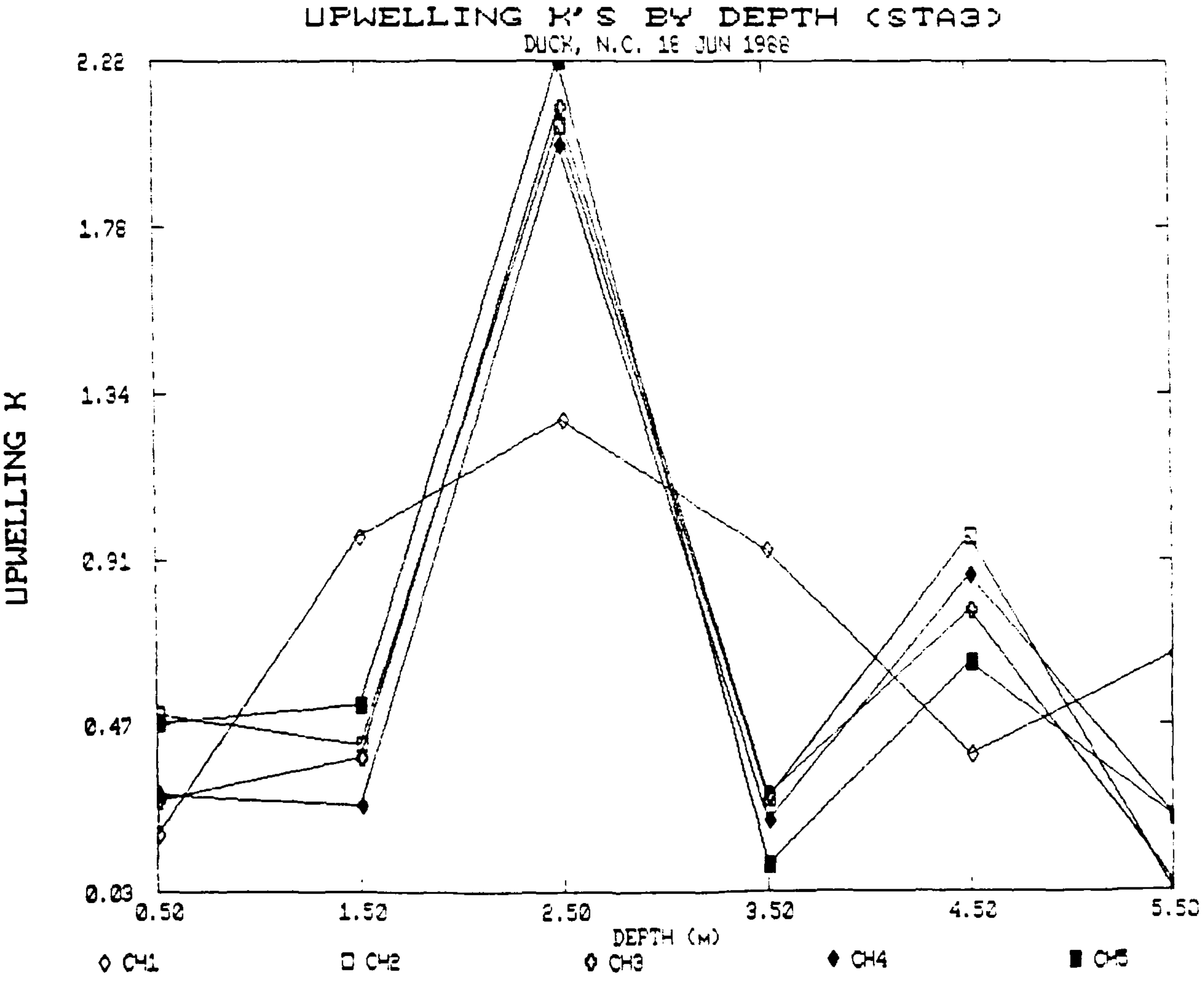

UPWELLING K'S BY DEPTH (STA3)
DUCK, N.C. 18 JUN 1988
2.22
1.78
1.34
0.91
0.47
0.03
UPWELLING K
0.50
1.50
2.50
3.50
4.50
5.50
DEPTH (M)
◇ CH1
□ CH2
◇ CH3
◆ CH4
■ CH5

FIG. 30.

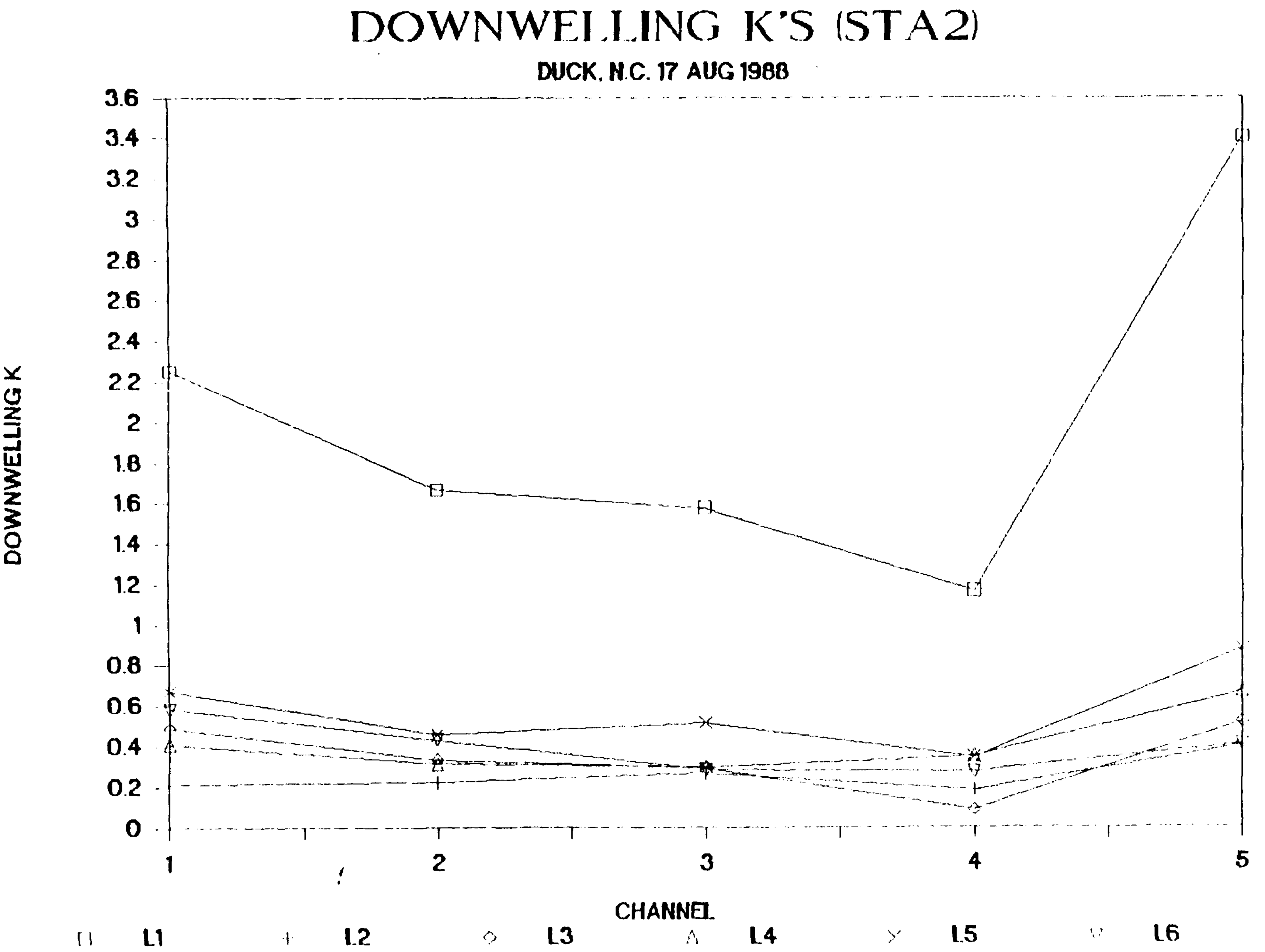

DOWNWELLING K'S (STA2)
DUCK, N.C. 17 AUG 1988
DOWNWELLING K
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
CHANNEL
L1
L2
L3
L4
L5
L6

FIG. 31.

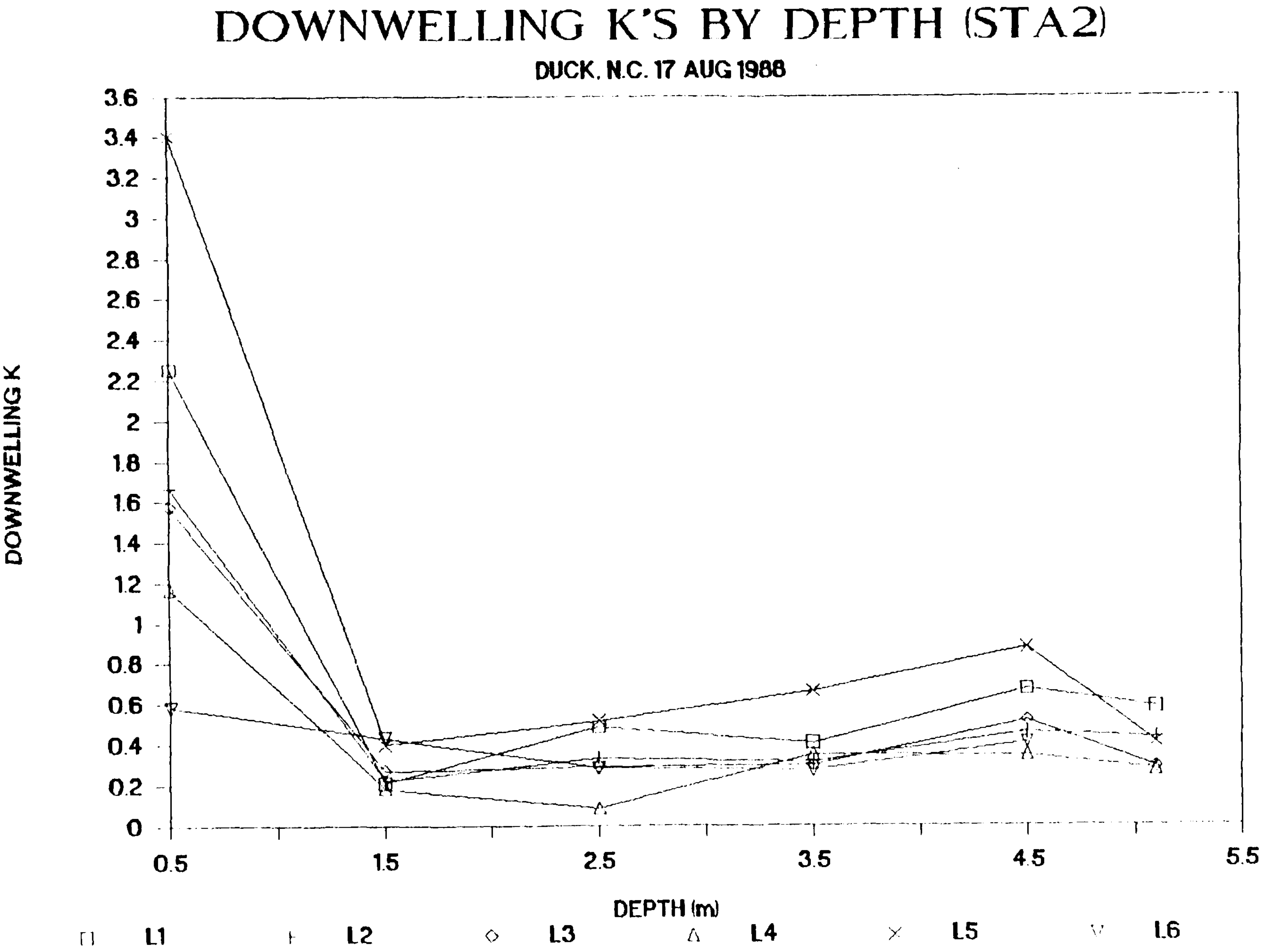

DOWNWELLING K'S BY DEPTH (STA2)
DUCK, N.C. 17 AUG 1988
DOWNWELLING K
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0.5
1.5
2.5
3.5
4.5
5.5
DEPTH (m)
□ L1
+ L2
◇ L3
△ L4
× L5
▽ L6

FIG. 32.

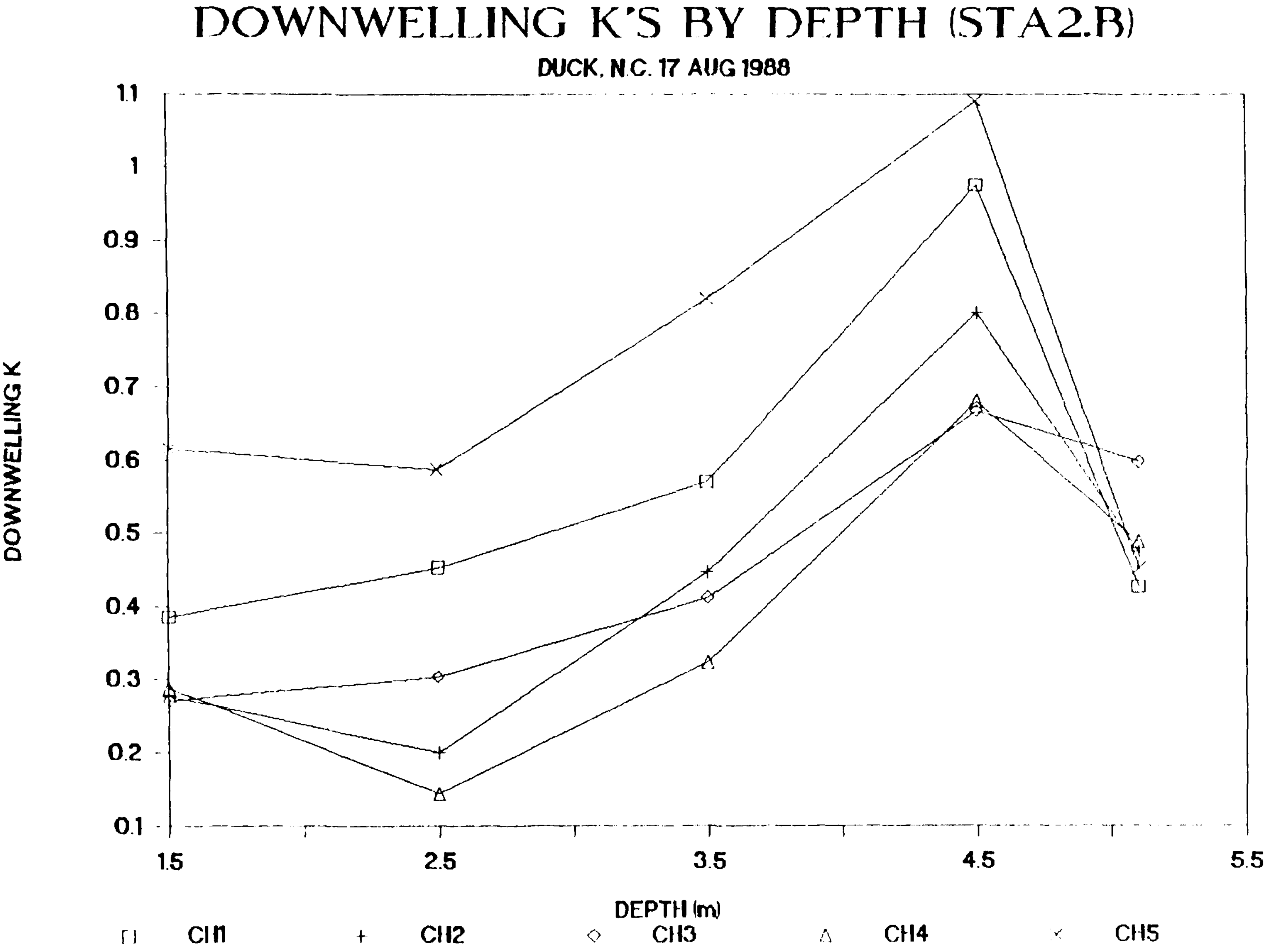

DOWNWELLING K'S BY DEPTH (STA2.B)
DUCK, N.C. 17 AUG 1988
DOWNWELLING K
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1.5
2.5
3.5
4.5
5.5
DEPTH (m)
□ CH1
+ CH2
◇ CH3
△ CH4
× CH5

FIG. 33.

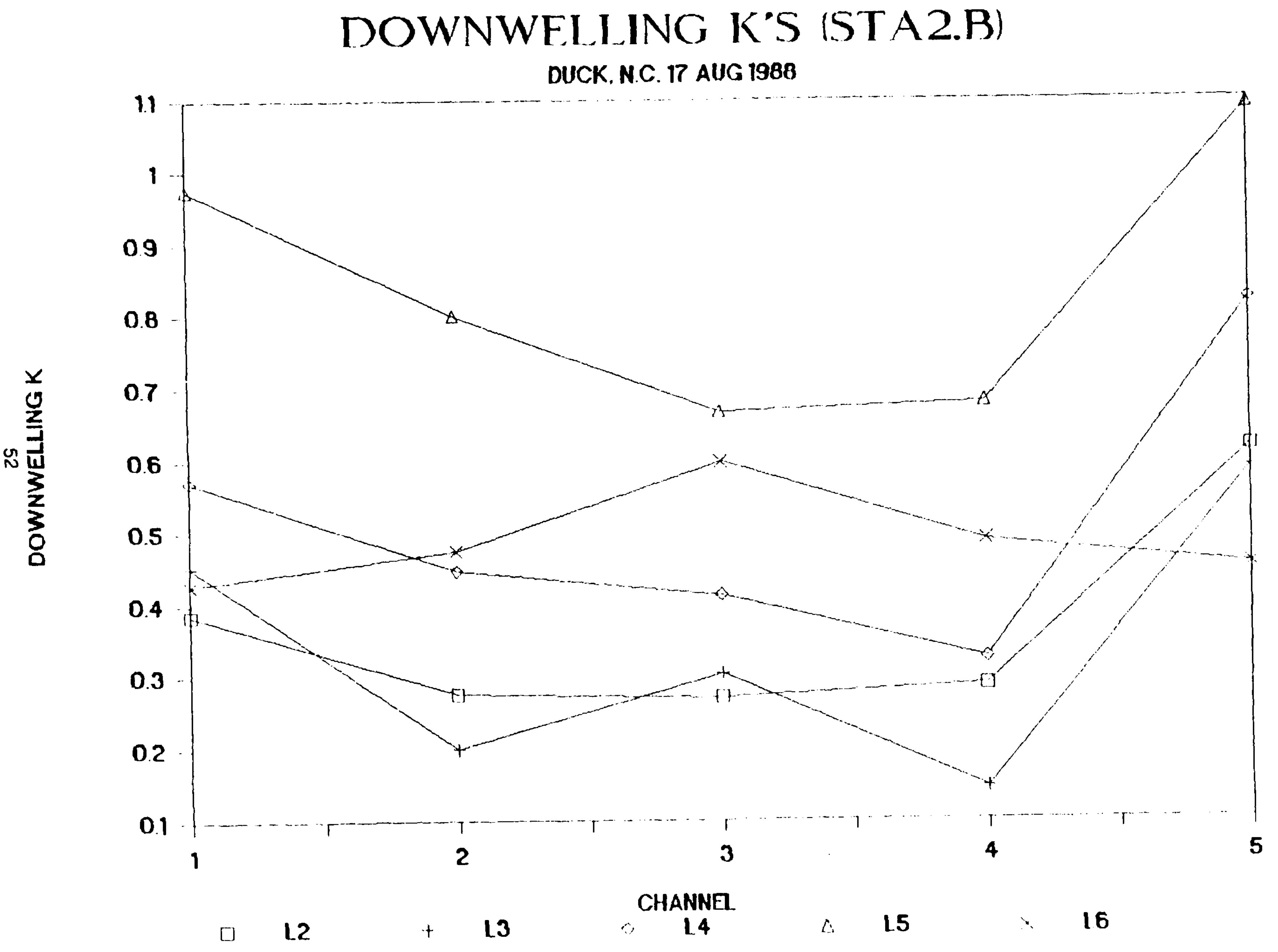

DOWNWELLING K'S (STA2.B)
DUCK, N.C. 17 AUG 1988
DOWNWELLING K
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
CHANNEL
□ L2
+ L3
◇ L4
△ L5
× L6

FIG. 34

DOWNWELLING K'S (STA3)

DUCK, N.C. 17 AUG 1988

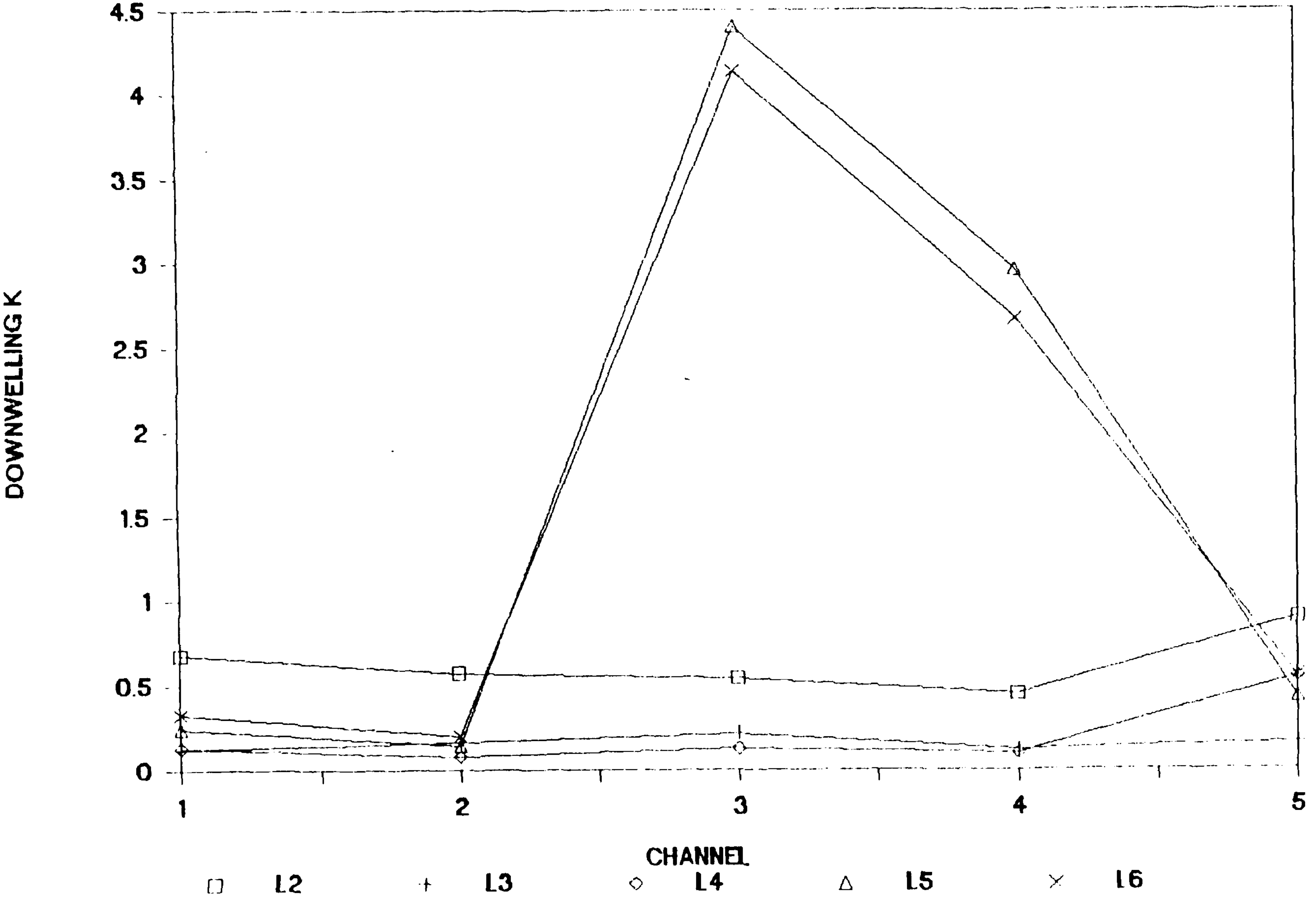
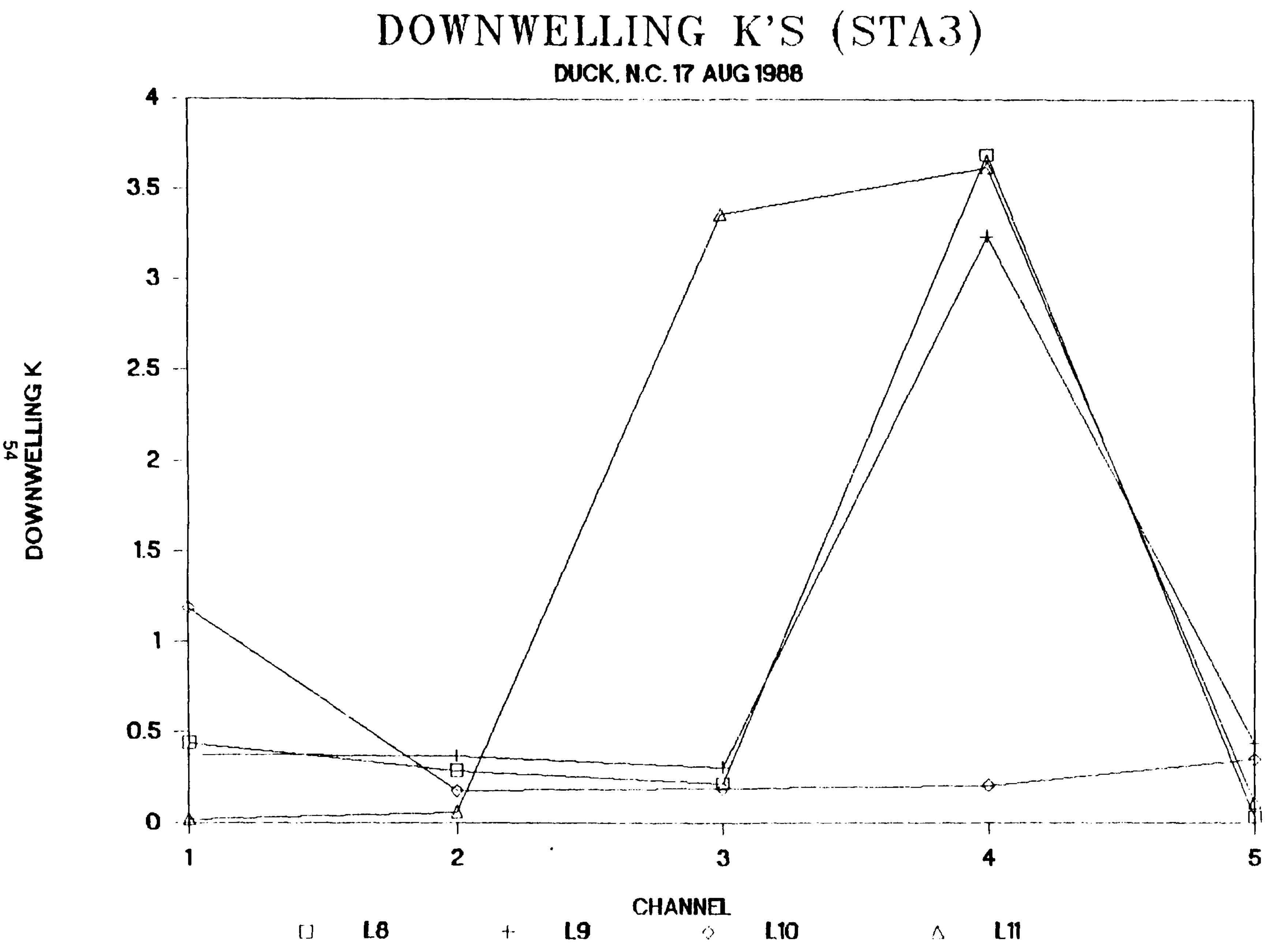


FIG. 35.


DOWNWELLING K'S (STA3)

DUCK, N.C. 17 AUG 1988

FIG 36

DOWNWELLING K'S BY DEPTH (STA3)

DUCK, N.C. 17 AUG 1988

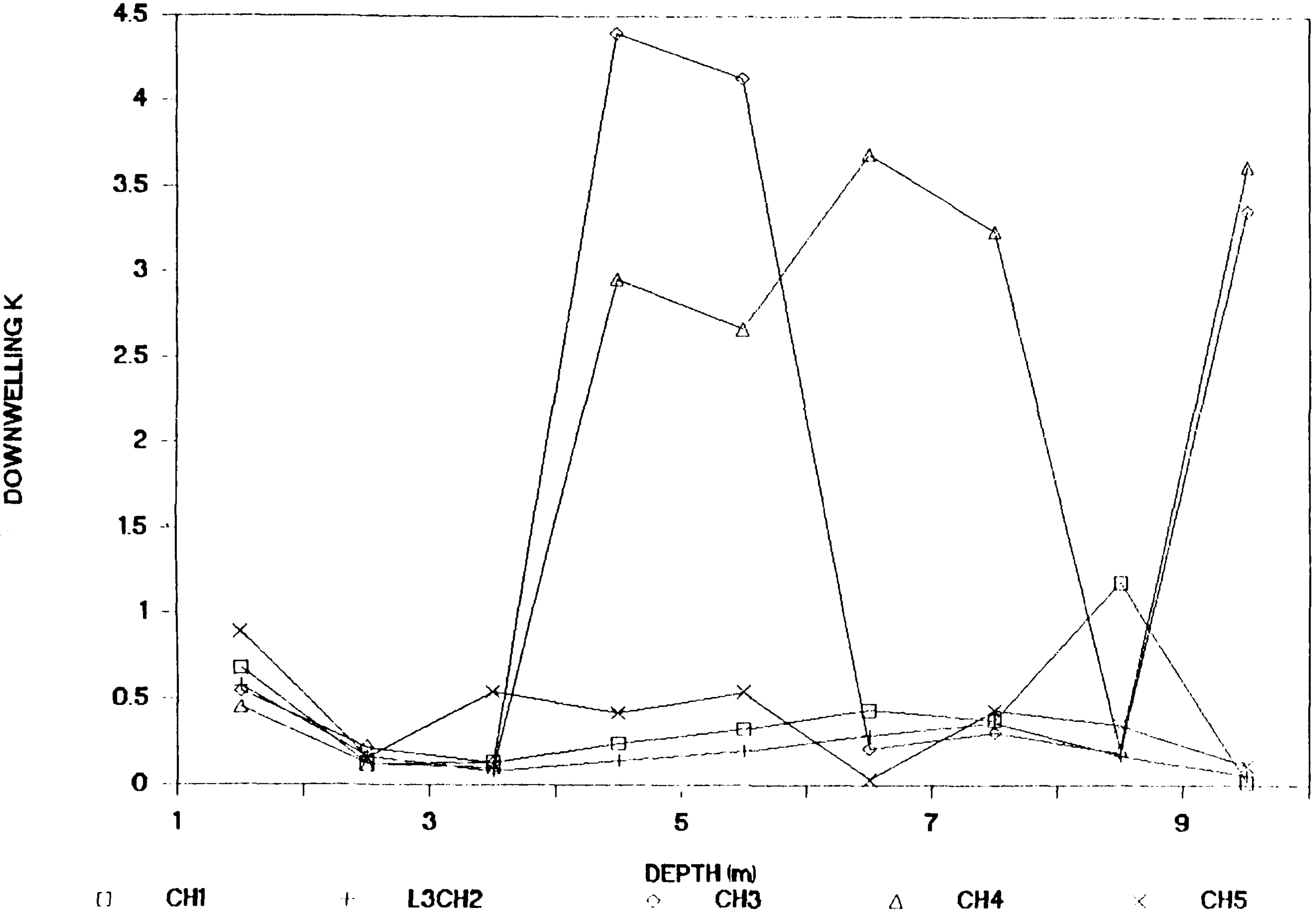


FIG. 37

UPWELLING K'S BY DEPTH (STA2)

DUCK, N.C. 17 AUG 1988

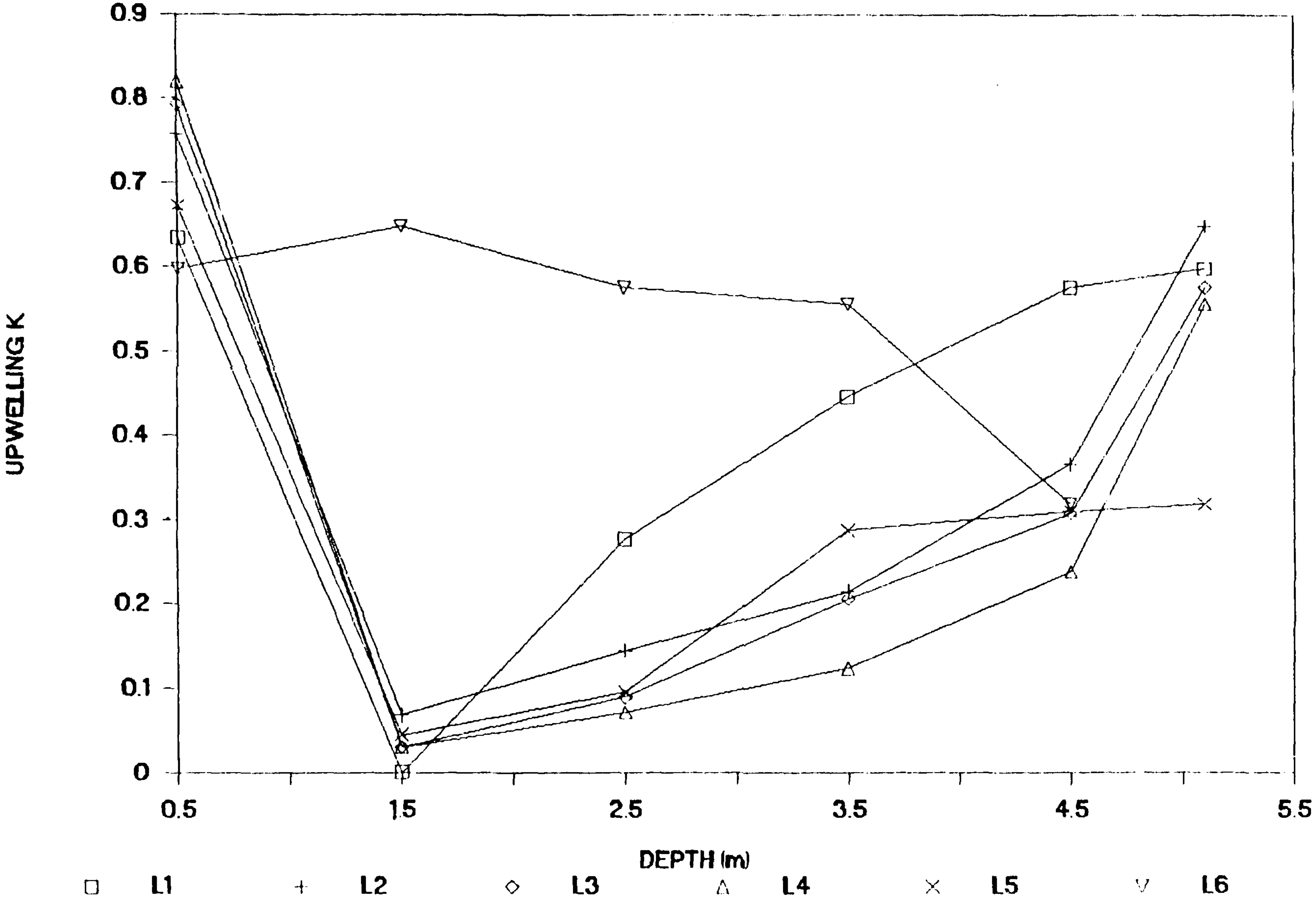


FIG 38

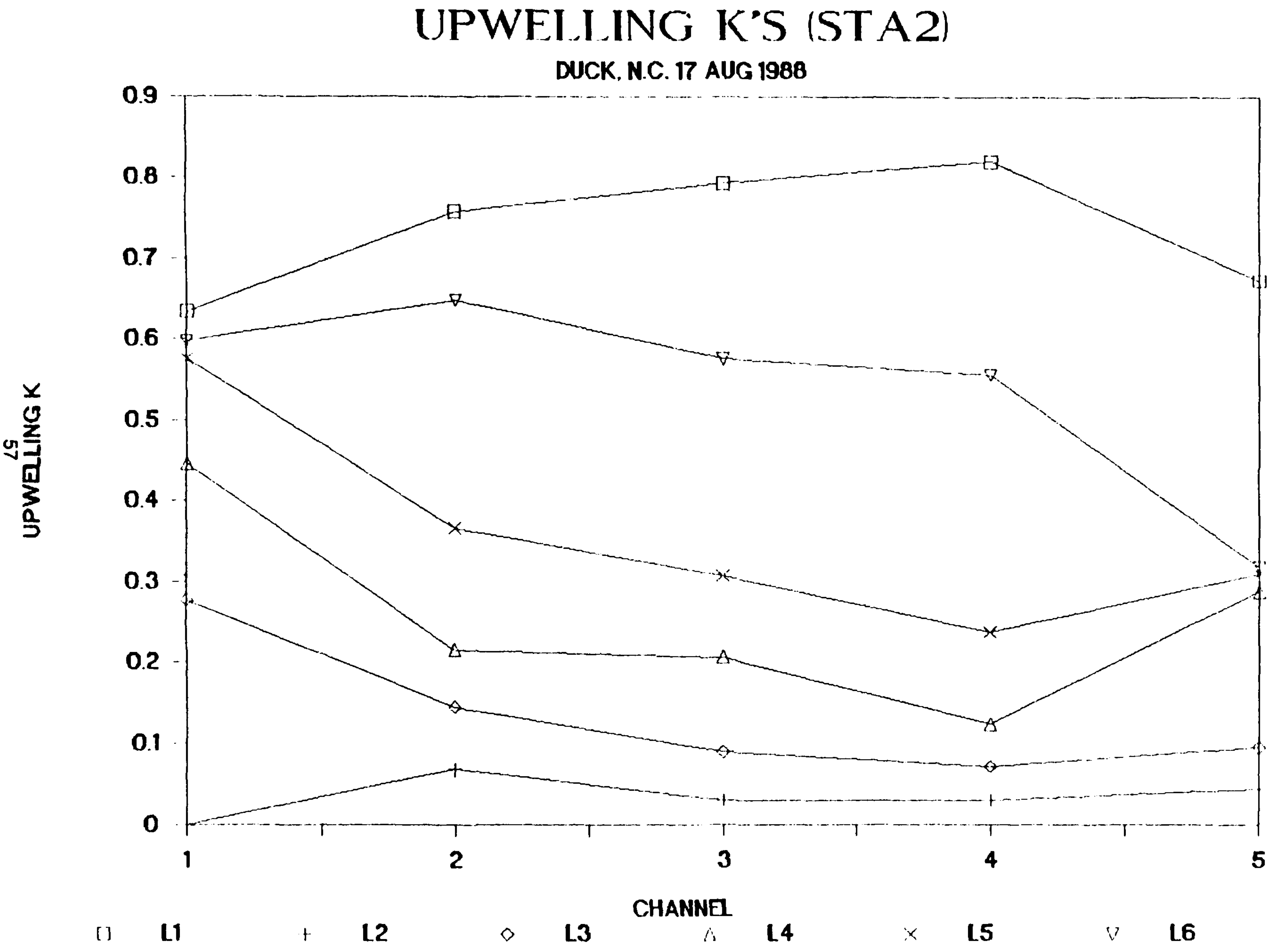
UPWELLING K'S (STA2)
DUCK, N.C. 17 AUG 1988
UPWELLING K
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
CHANNEL
□ L1
+ L2
◇ L3
△ L4
× L5
▽ L6

FIG. 39.

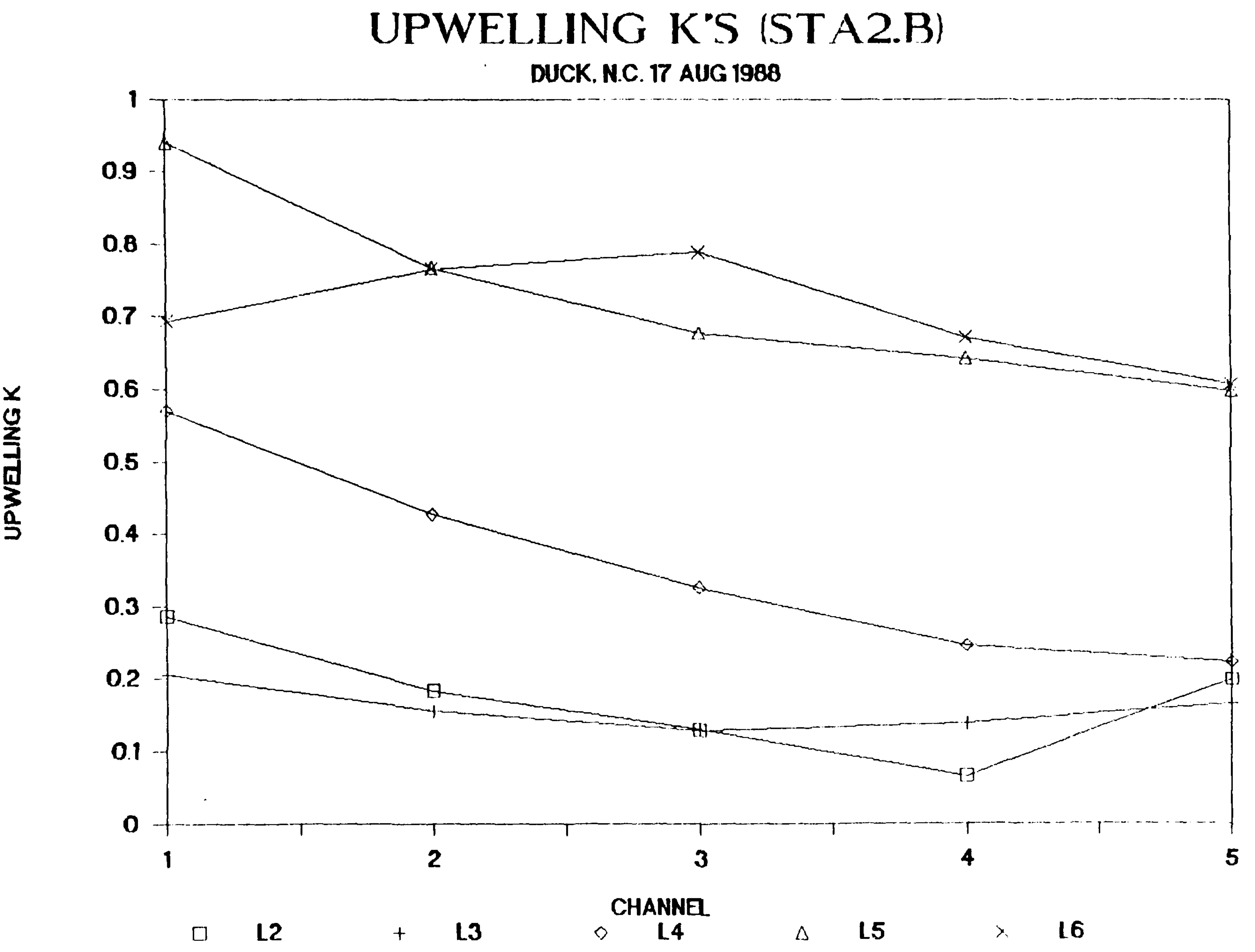

UPWELLING K'S (STA2.B)
DUCK, N.C. 17 AUG 1988
UPWELLING K
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
CHANNEL
□ L2
+ L3
◇ L4
△ L5
× L6

FIG. 40

UPWELLING K'S BY DEPTH (STA2.B)

DUCK, N.C. 17 AUG 1988

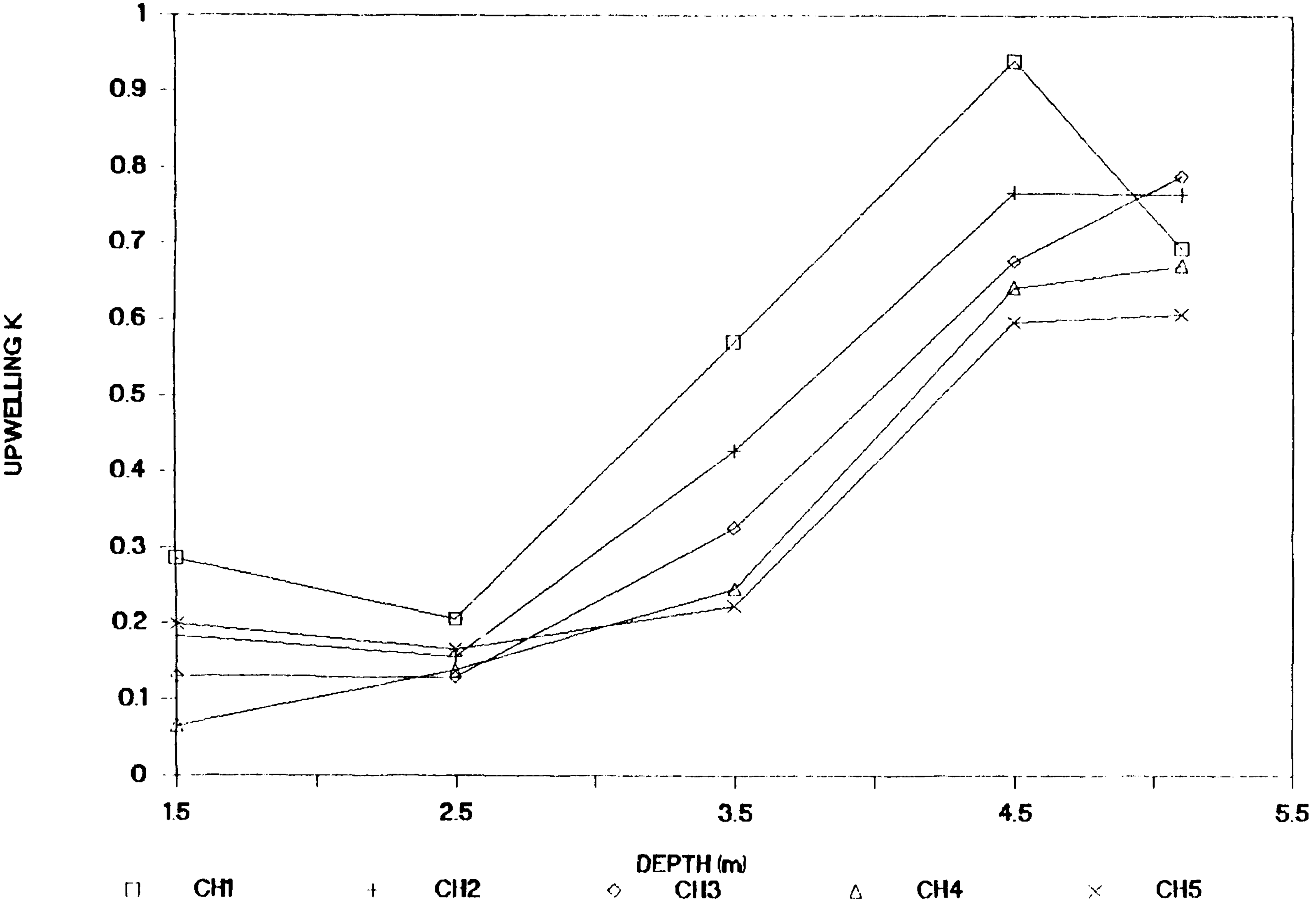


FIG. 41.

UPWELLING K'S BY DEPTH (STA3)

DUCK. N.C. 17 AUG 1988

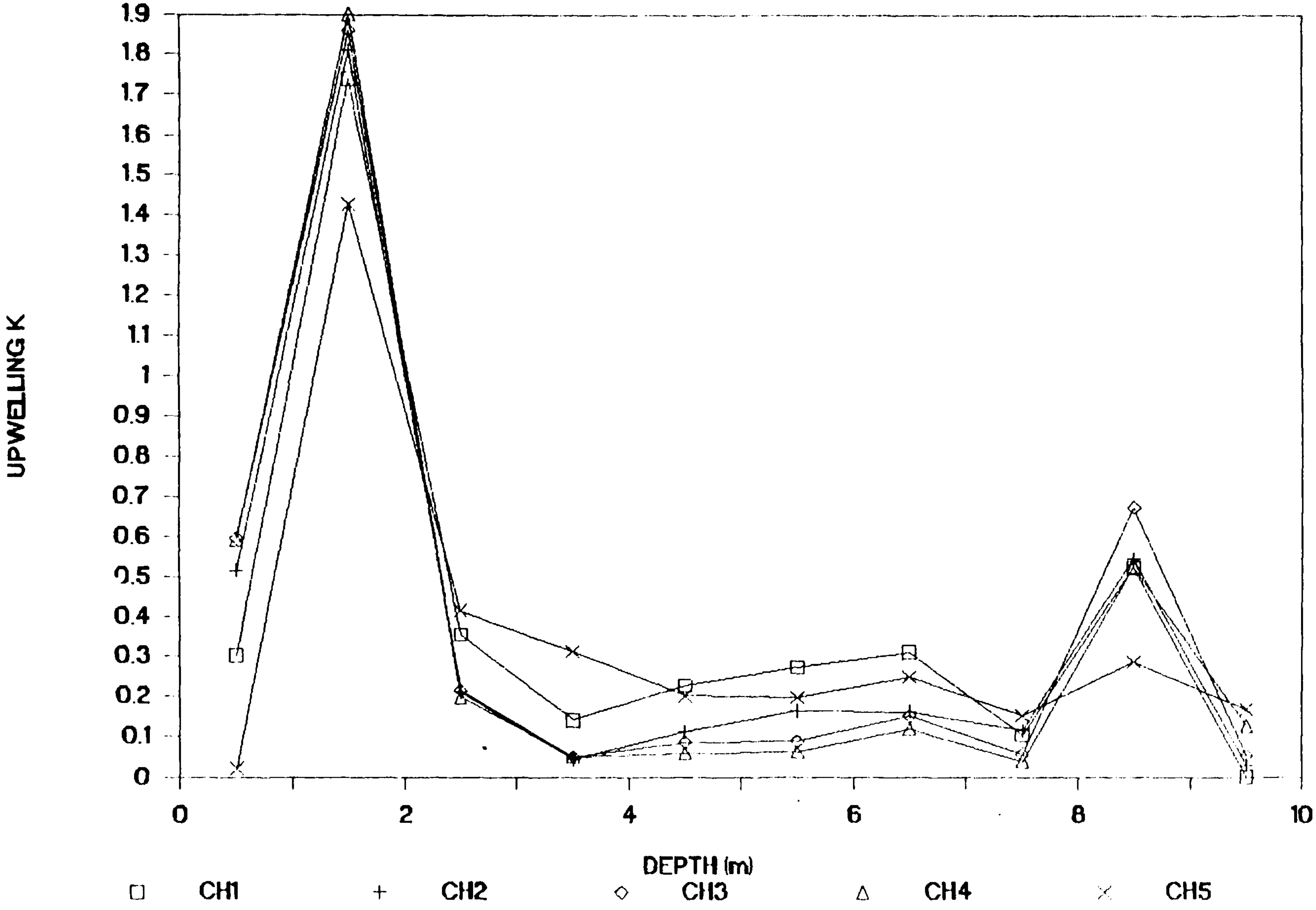


FIG 42

UPWELLING K'S (STA3)

DUCK, N.C. 17 AUG 1988

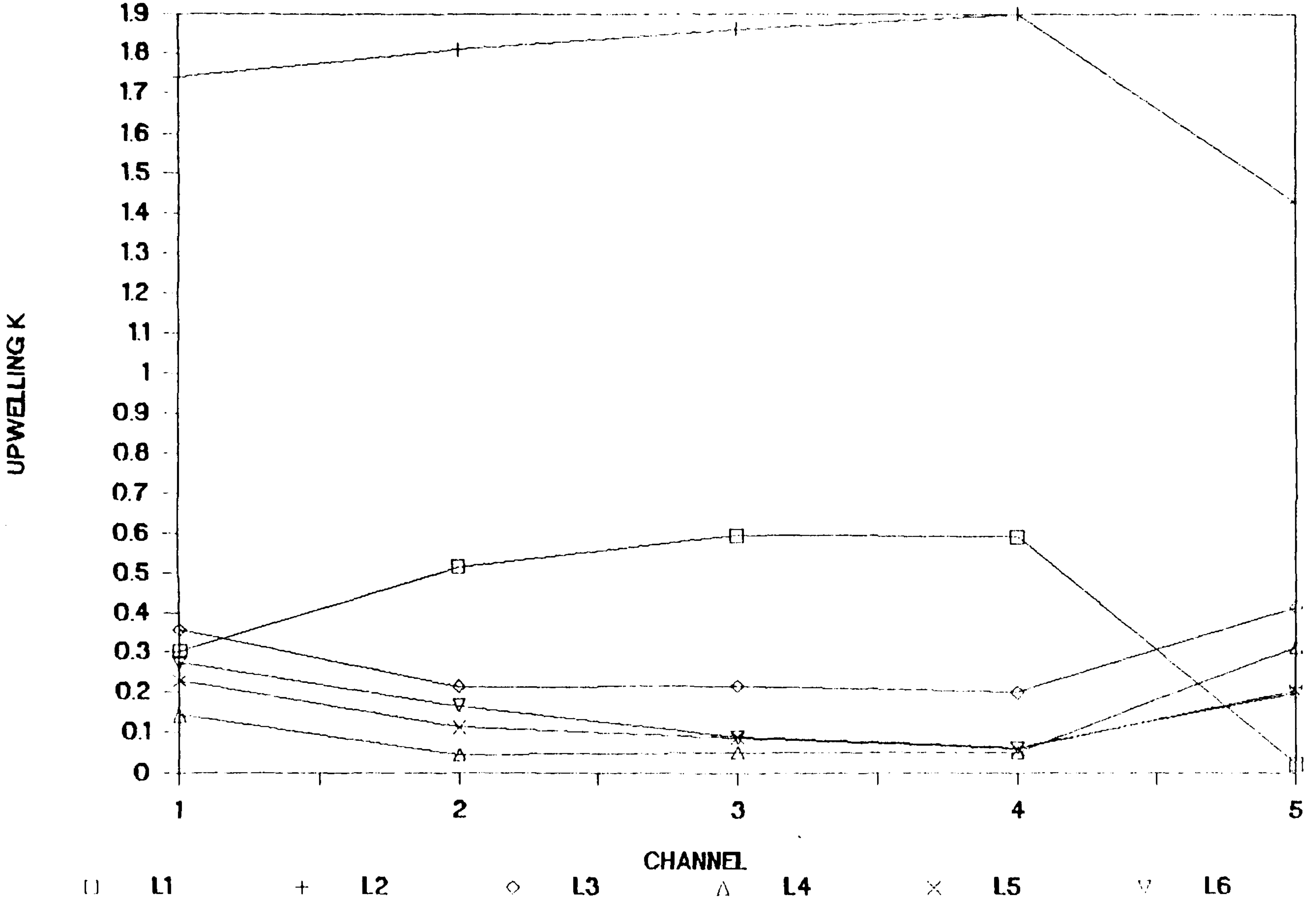


FIG. 43.

UPWELLING K'S (STA3)

DUCK. N.C. 17 AUG 1988

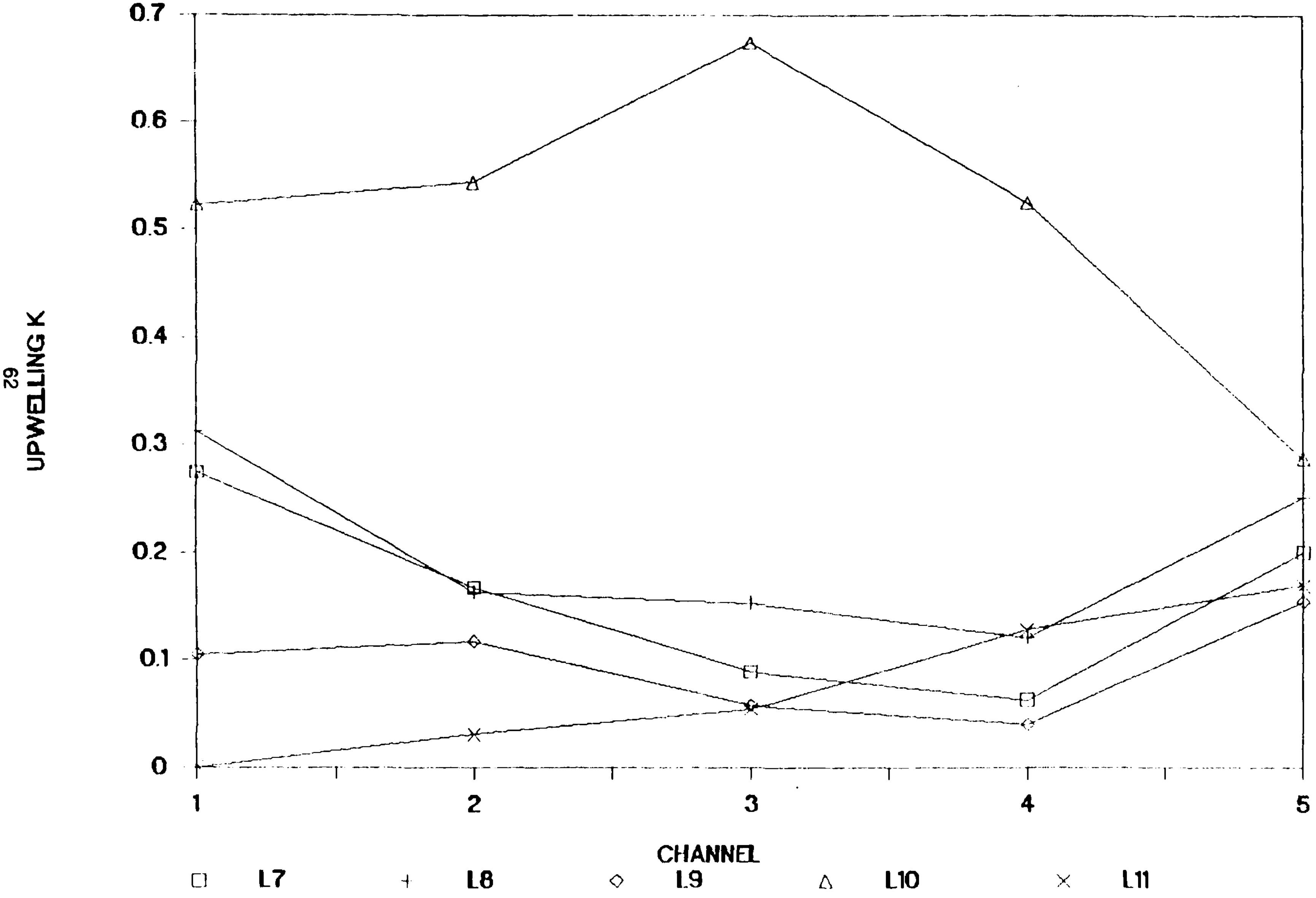


Fig 44

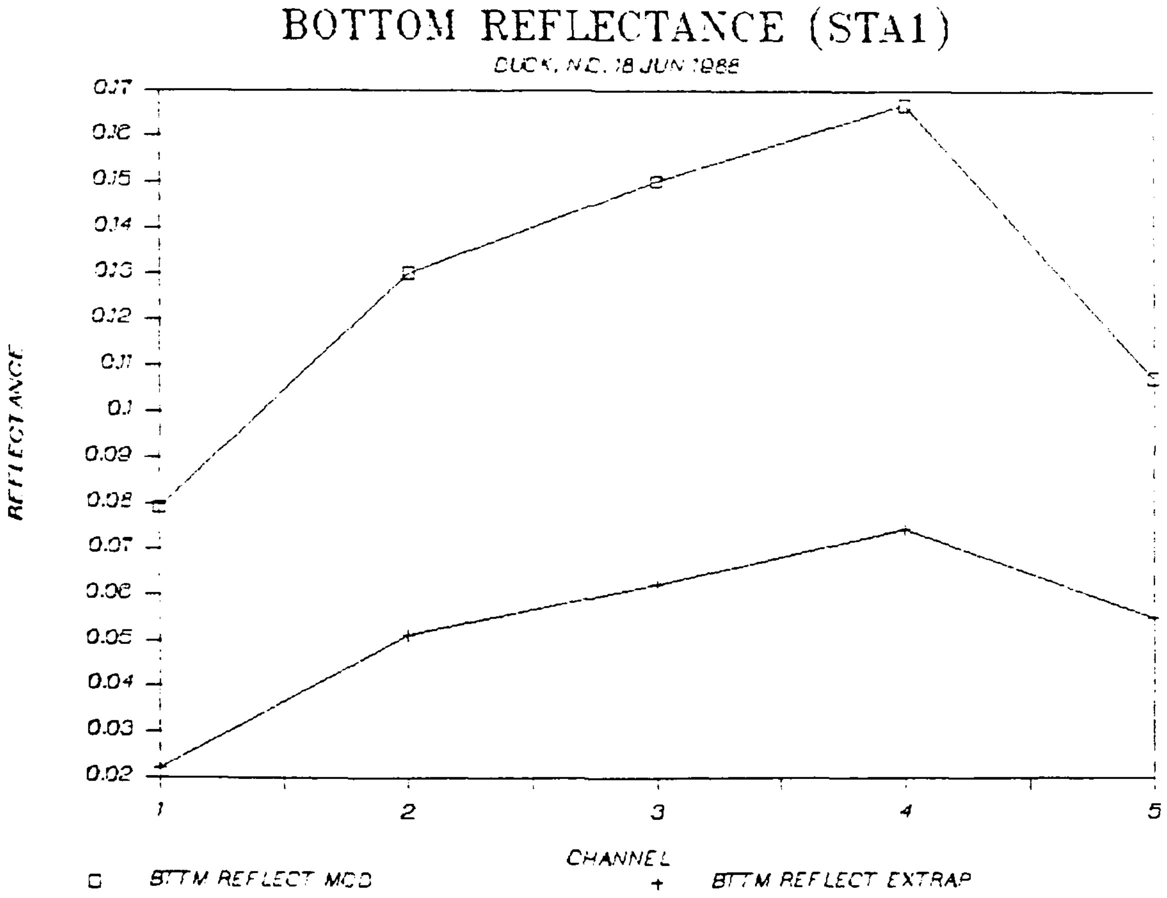

BOTTOM REFLECTANCE (STA1)
DUCK, N.C. 18 JUN 1988
REFLECTANCE
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
1
2
3
4
5
CHANNEL
□ BTTM REFLECT MOD
+ BTTM REFLECT EXTRAP

FIG. 45.

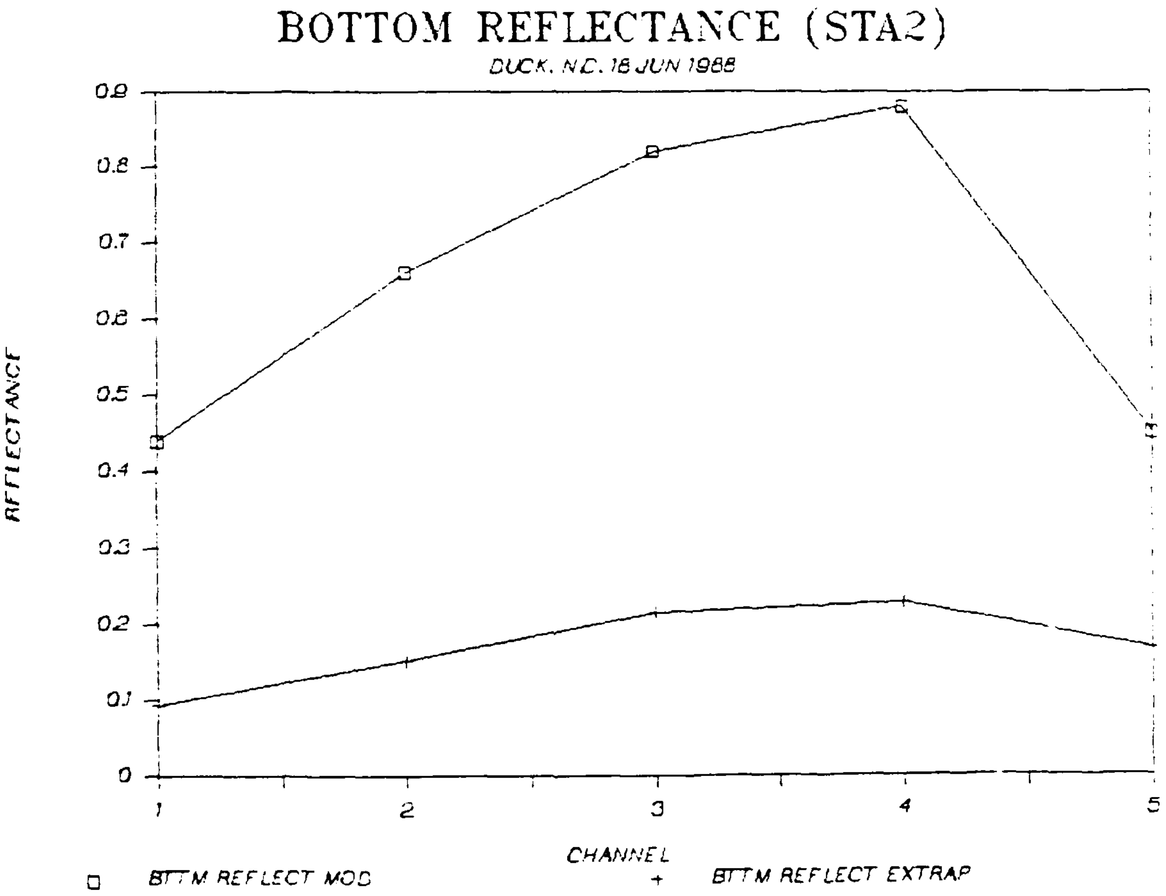

BOTTOM REFLECTANCE (STA2)
DUCK, N.C. 18 JUN 1988
REFLECTANCE
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1
2
3
4
5
CHANNEL
□ BTTM REFLECT MOD
+ BTTM REFLECT EXTRAP

FIG. 46.

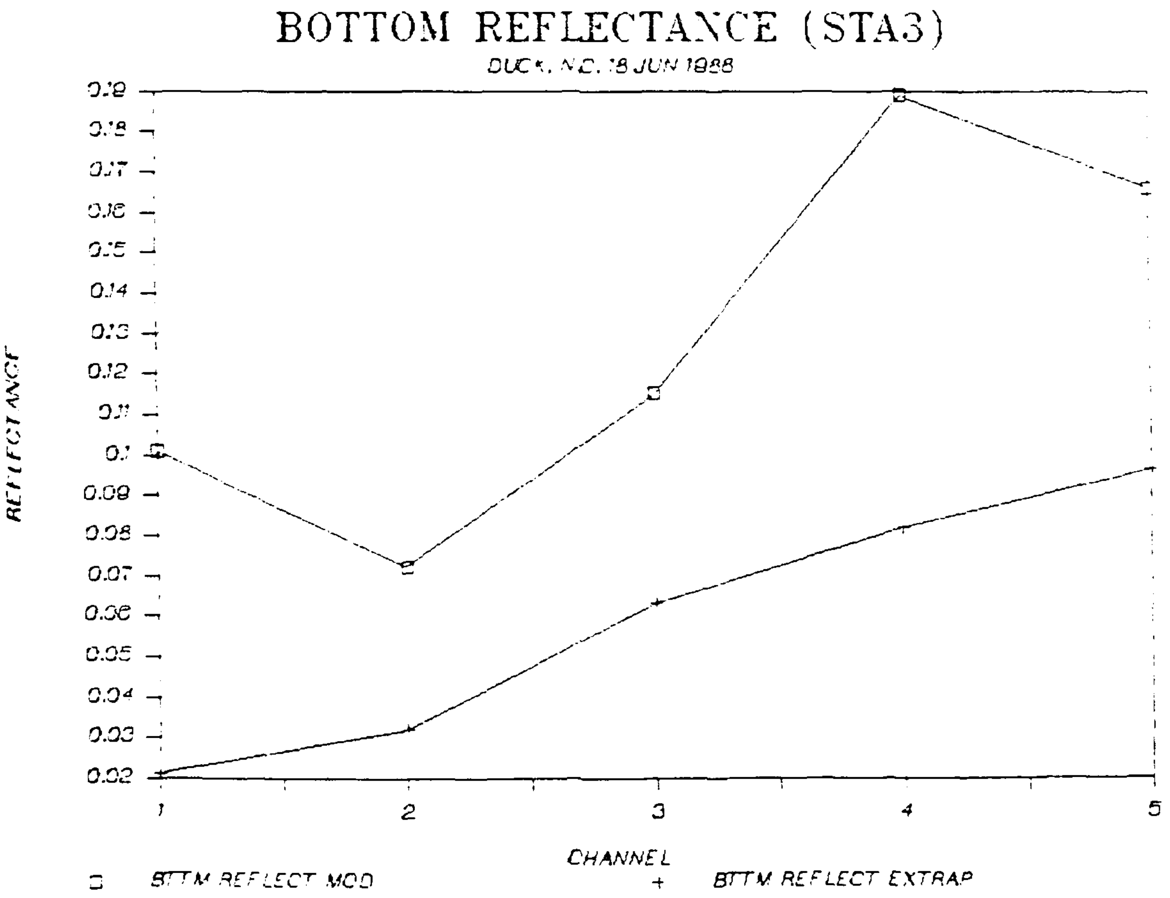

BOTTOM REFLECTANCE (STA3)
DUCK, N.C. 18 JUN 1988
0.19
0.18
0.17
0.16
0.15
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
REFLECTANCE
1
2
3
4
5
CHANNEL
□ BTTM REFLECT MOD
+ BTTM REFLECT EXTRAP

FIG. 47.

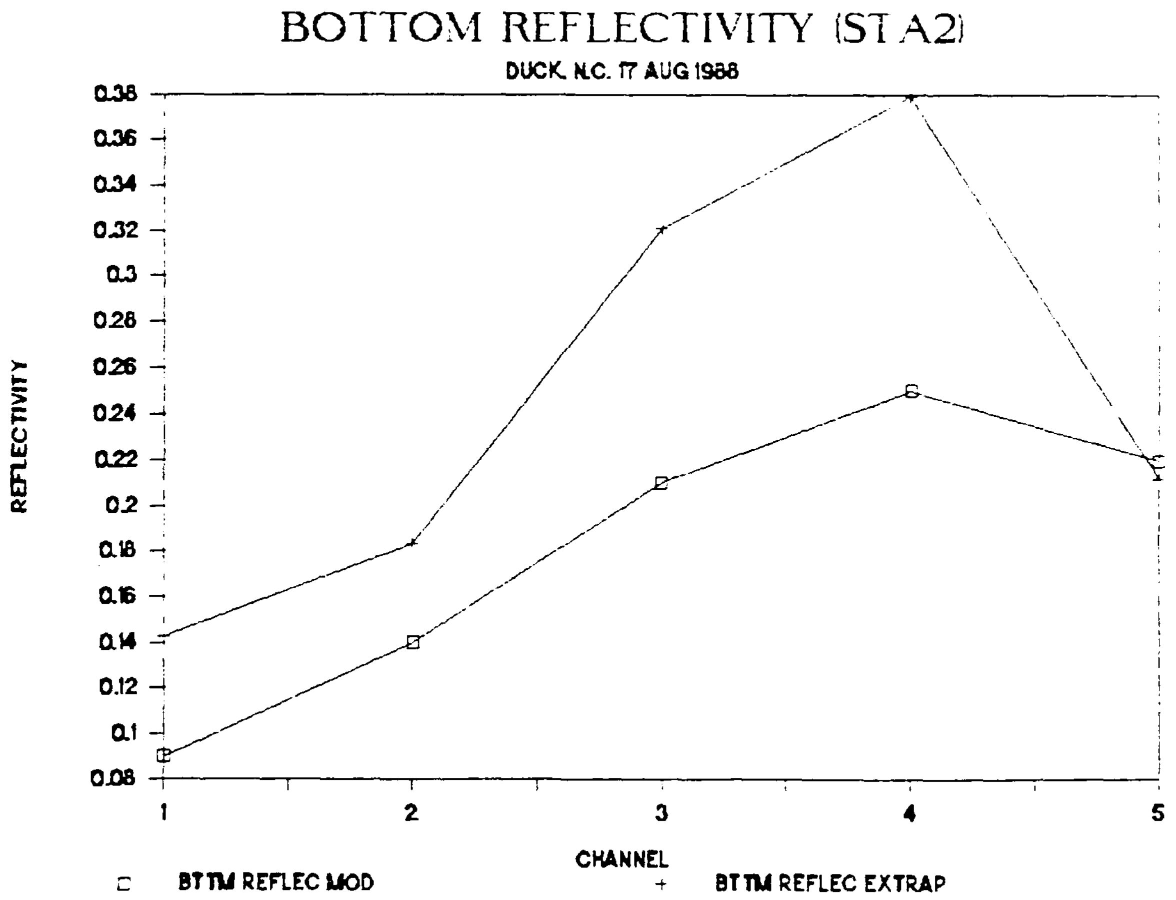

BOTTOM REFLECTIVITY (ST A2)
DUCK, N.C. 17 AUG 1988
REFLECTIVITY
0.38
0.36
0.34
0.32
0.3
0.28
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
1
2
3
4
5
CHANNEL
□ BTTM REFLEC MOD
+ BTTM REFLEC EXTRAP

FIG. 48.

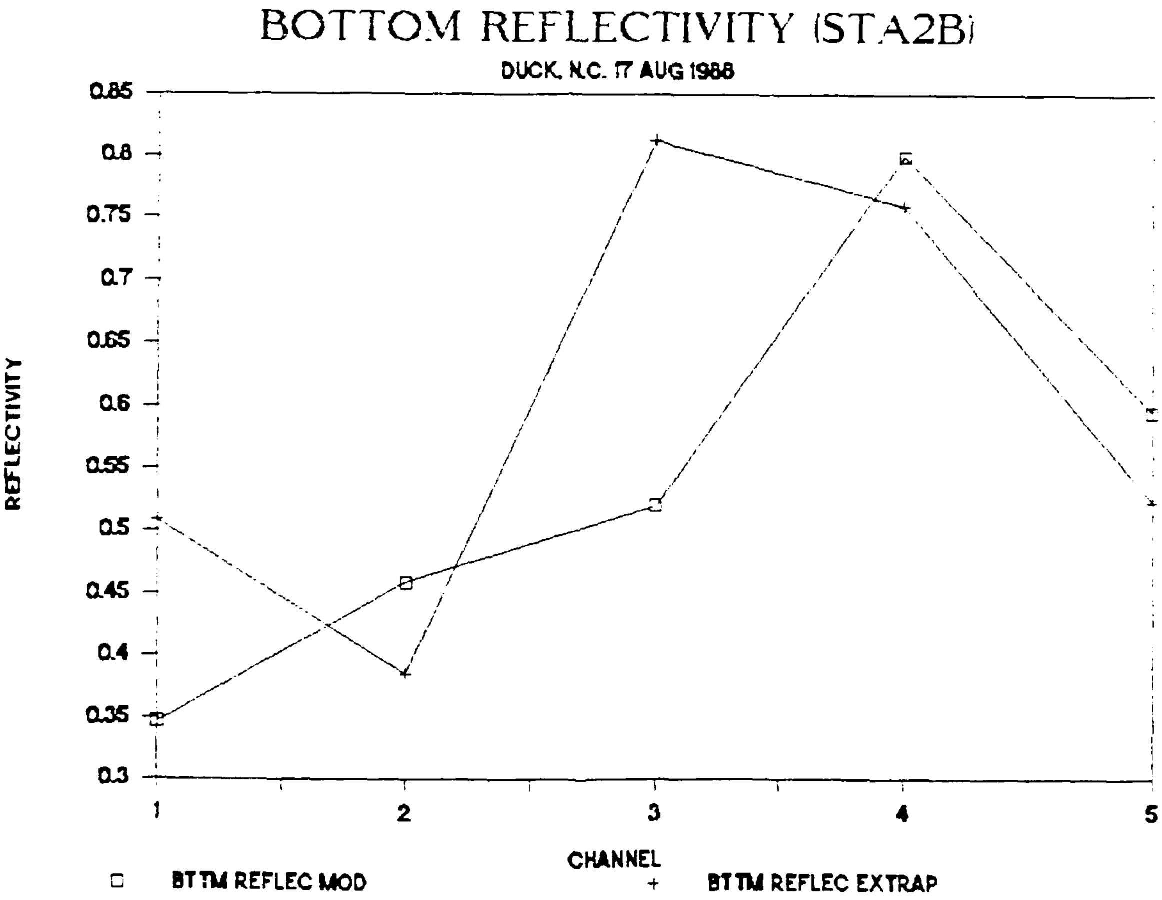

BOTTOM REFLECTIVITY (STA2B)
DUCK, N.C. 17 AUG 1988
REFLECTIVITY
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
0.4
0.35
0.3
1
2
3
4
5
CHANNEL
□ BTTM REFLEC MOD
+ BTTM REFLEC EXTRAP

FIG. 49.

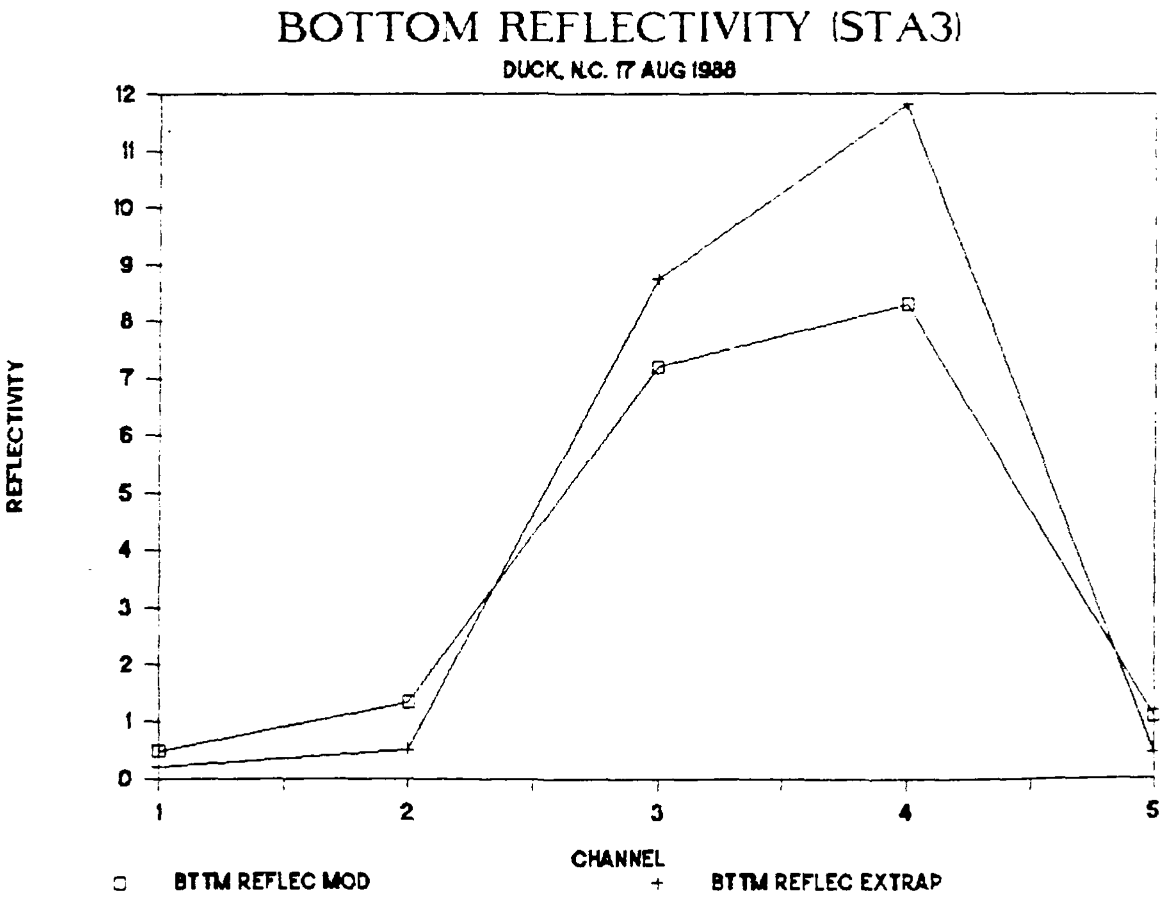

BOTTOM REFLECTIVITY (STA3)
DUCK, N.C. 17 AUG 1988
REFLECTIVITY
0
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
CHANNEL
□ BTTM REFLEC MOD
+ BTTM REFLEC EXTRAP

FIG. 50.

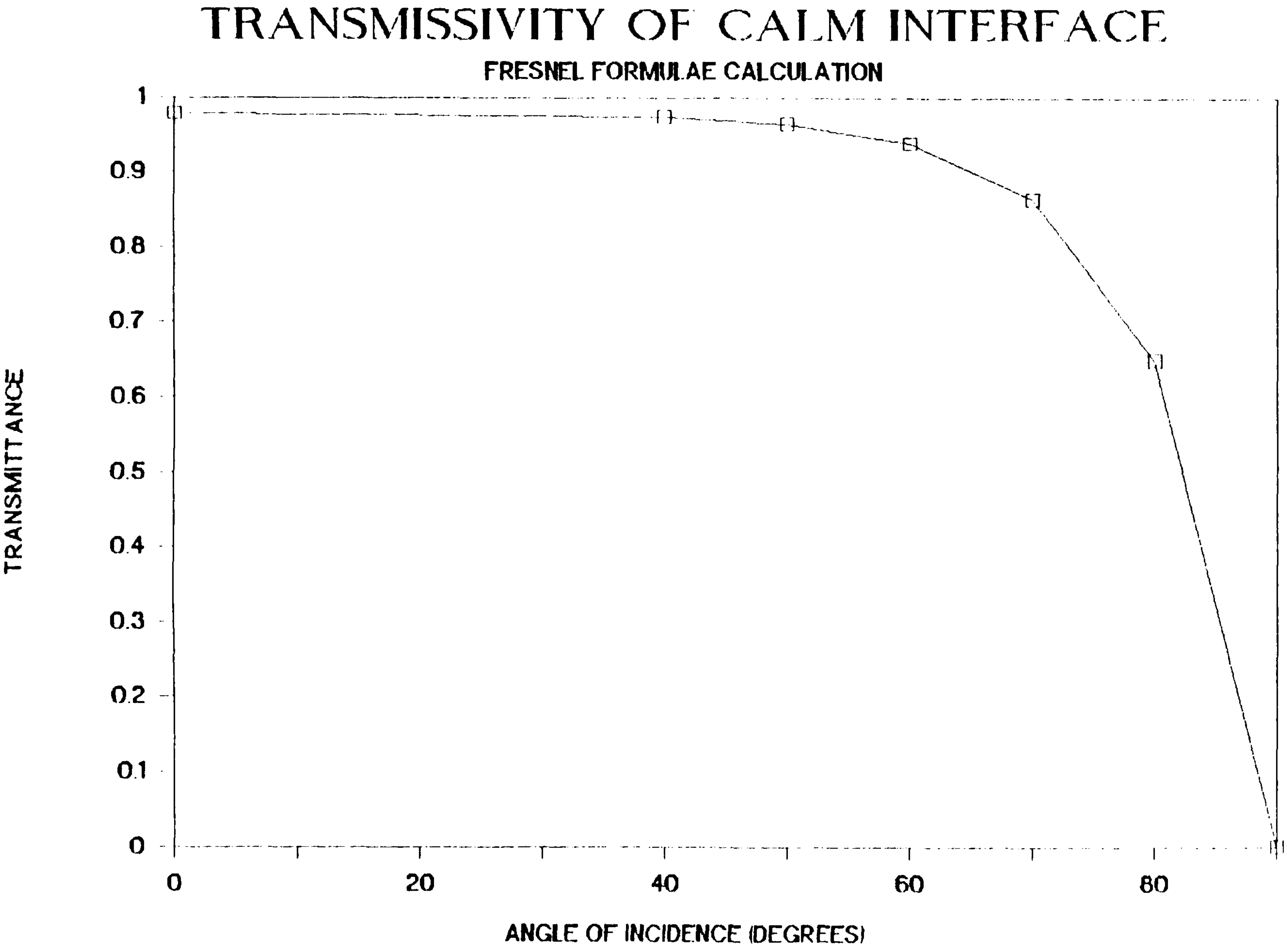
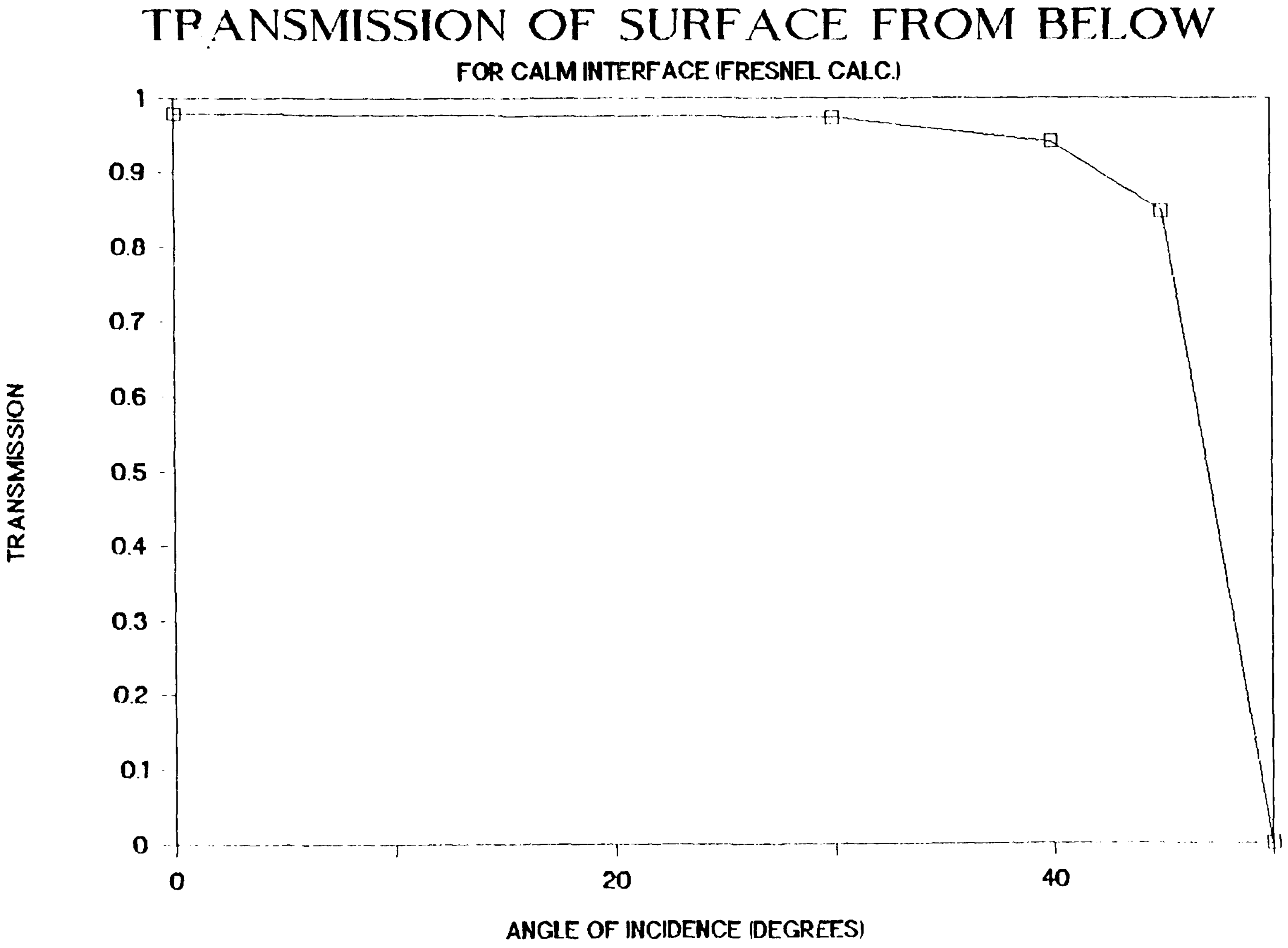

TRANSMISSIVITY OF CALM INTERFACE
FRESNEL FORMULAE CALCULATION
TRANSMITTANCE
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
20
40
60
80
ANGLE OF INCIDENCE (DEGREES)

FIG. 51.



TRANSMISSION OF SURFACE FROM BELOW

FOR CALM INTERFACE (FRESNEL CALC.)

FIG. 52.

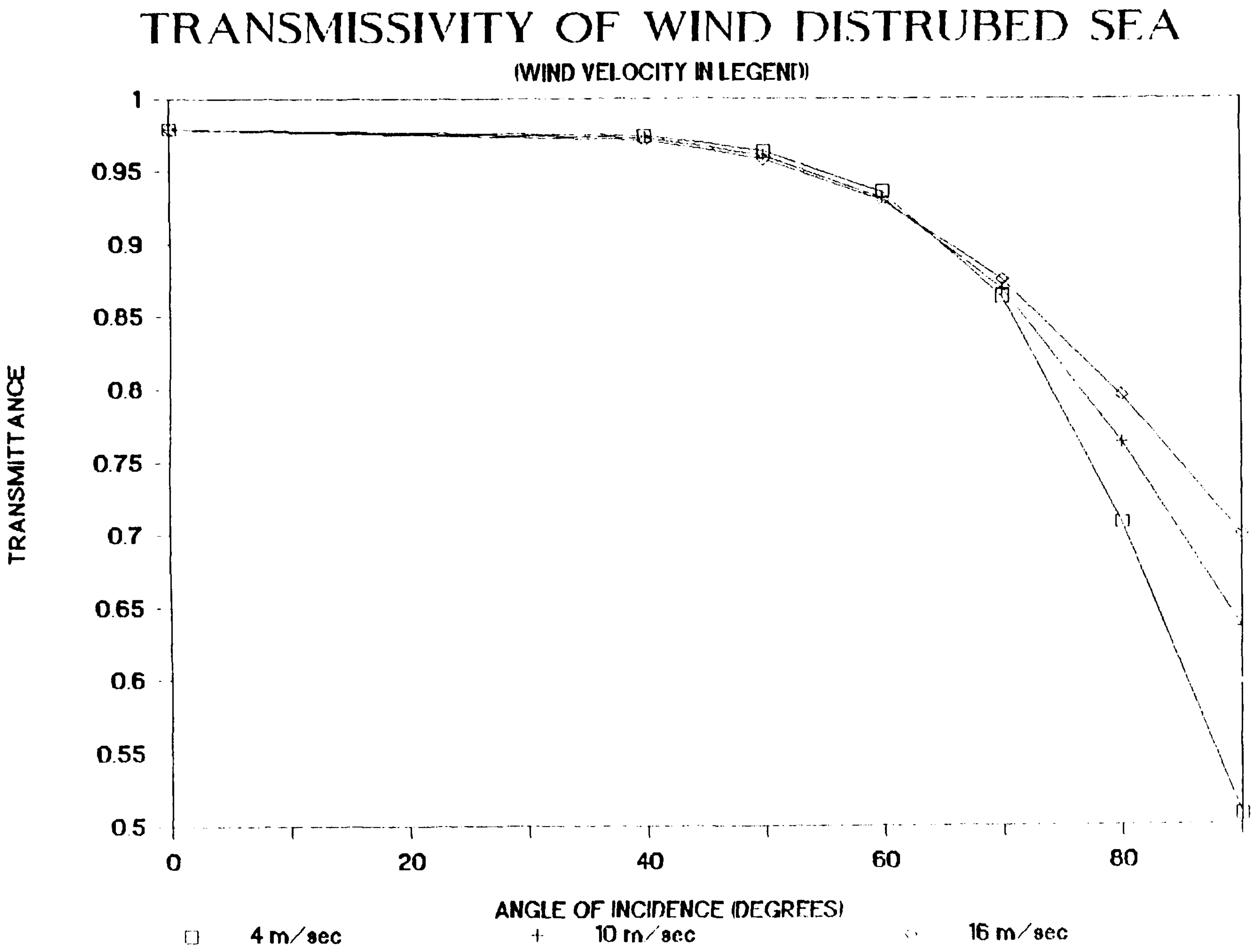

TRANSMISSIVITY OF WIND DISTRUBED SEA
(WIND VELOCITY IN LEGEND)
TRANSMITTANCE
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0
20
40
60
80
ANGLE OF INCIDENCE (DEGREES)
□ 4 m/sec
+ 10 m/sec
◇ 16 m/sec

FIG. 53.

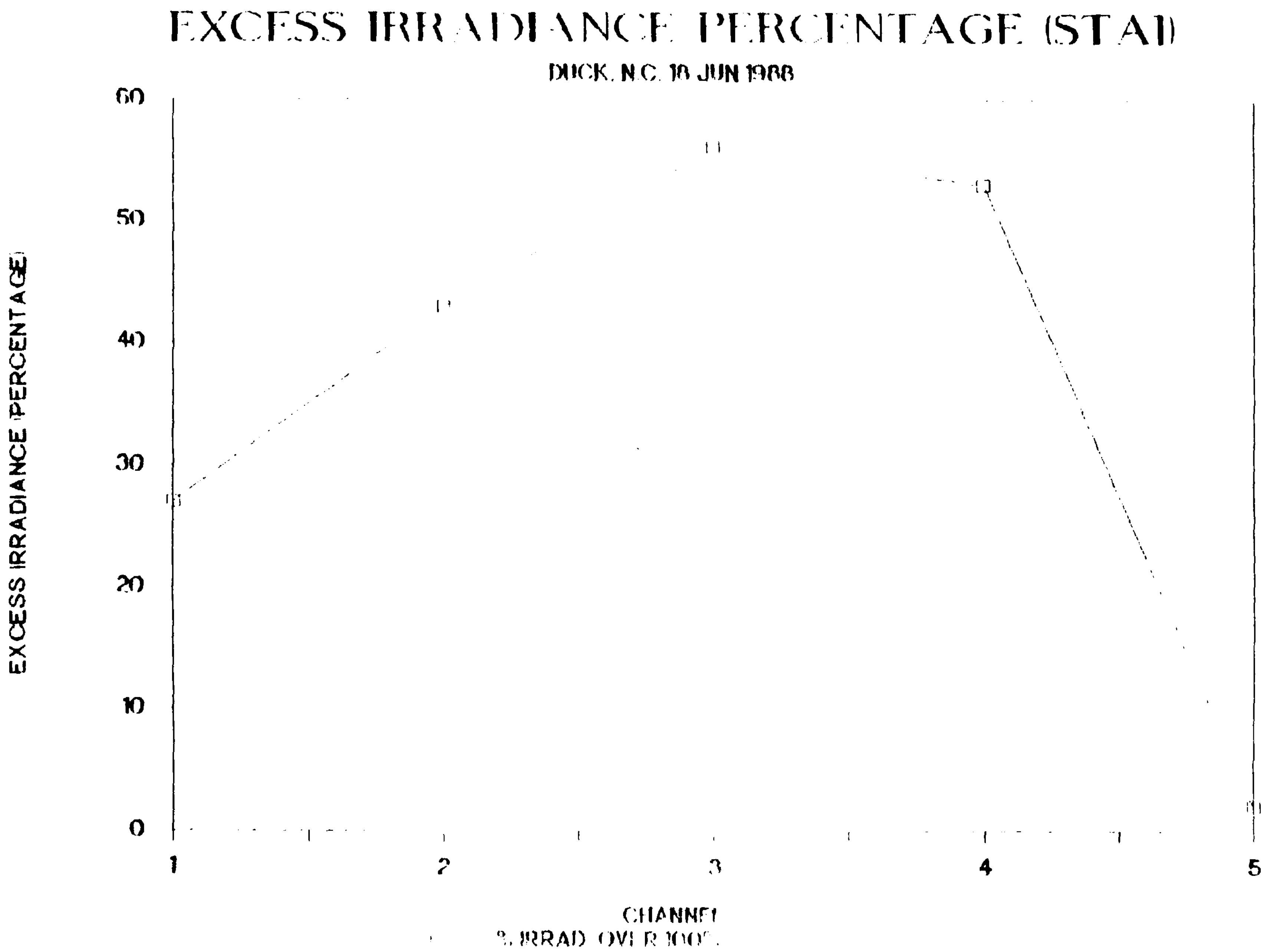
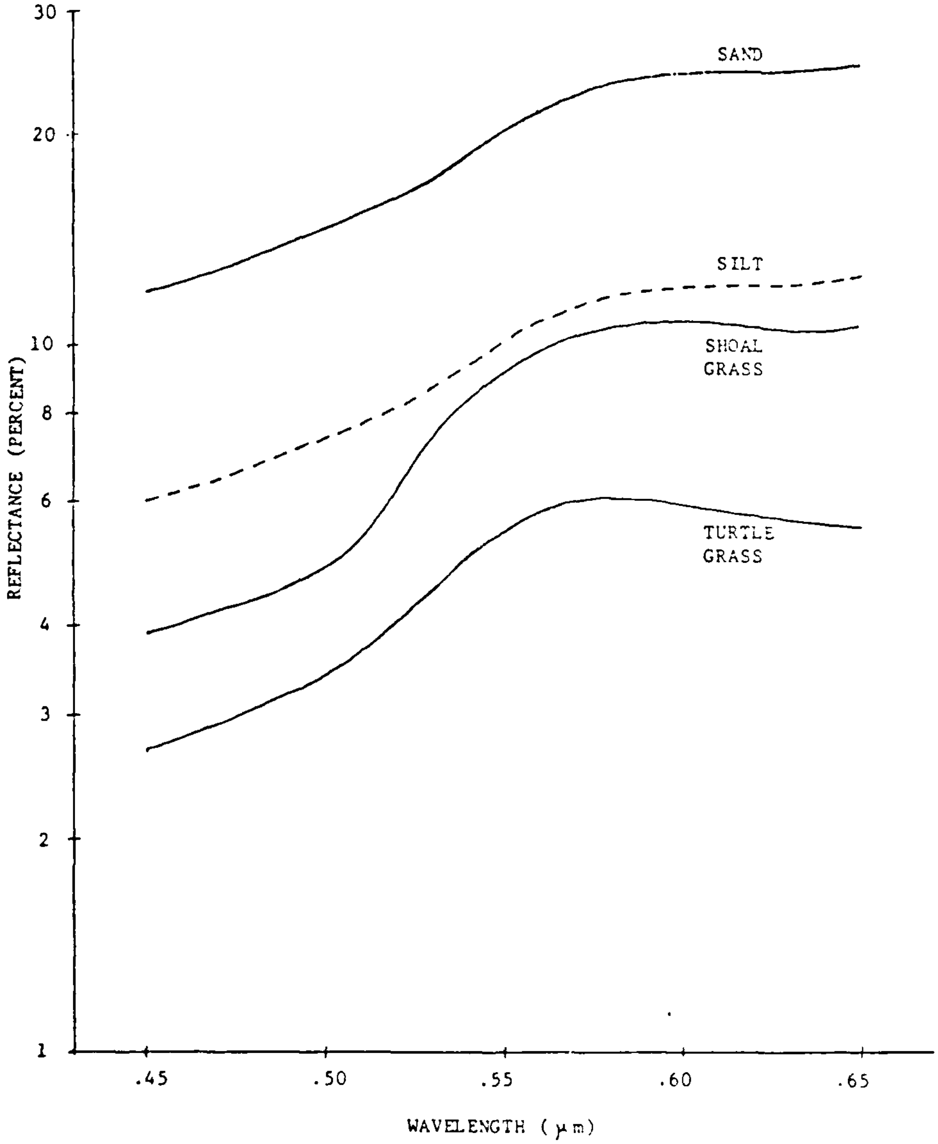

EXCESS IRRADIANCE PERCENTAGE (STA1)
DUCK, N.C. 18 JUN 1988
EXCESS IRRADIANCE PERCENTAGE
60
50
40
30
20
10
0
1
2
3
4
5
CHANNEL
% IRRAD OVER 100%

FIG. 54.

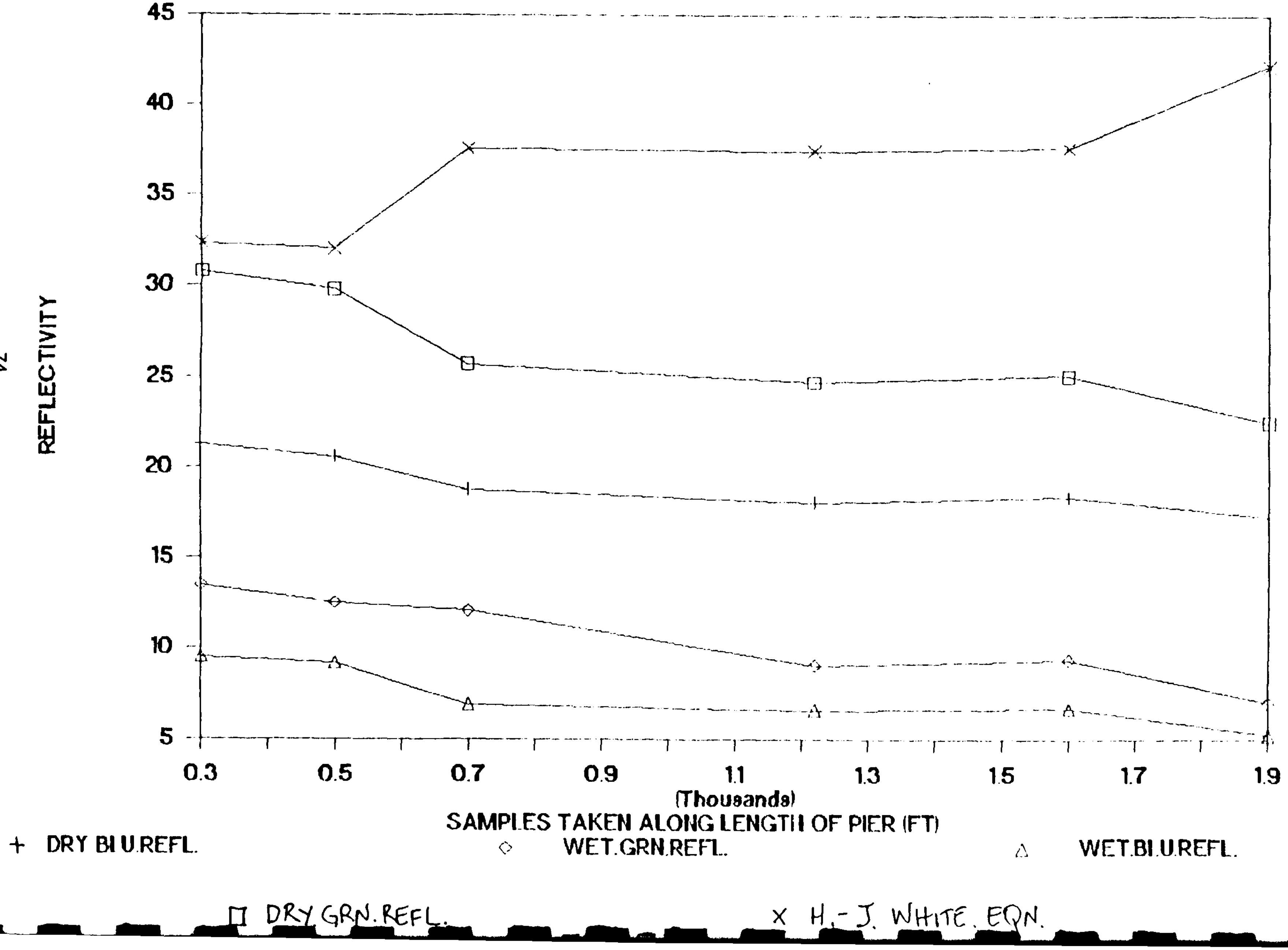


BOTTOM REFLECTANCES MEASURED FOR SAND, SHOAL GRASS, AND TURTLE GRASS IN ST. ANDREW BAY, FLORIDA. REFLECTANCE FOR SILT WAS INFERRED FROM SCANNER DATA.

FIG. 55

LAB. MEASURED BOTTOM SAMPLE REFLECTANCE

FOR BOTH DRY AND WET SAMPLES



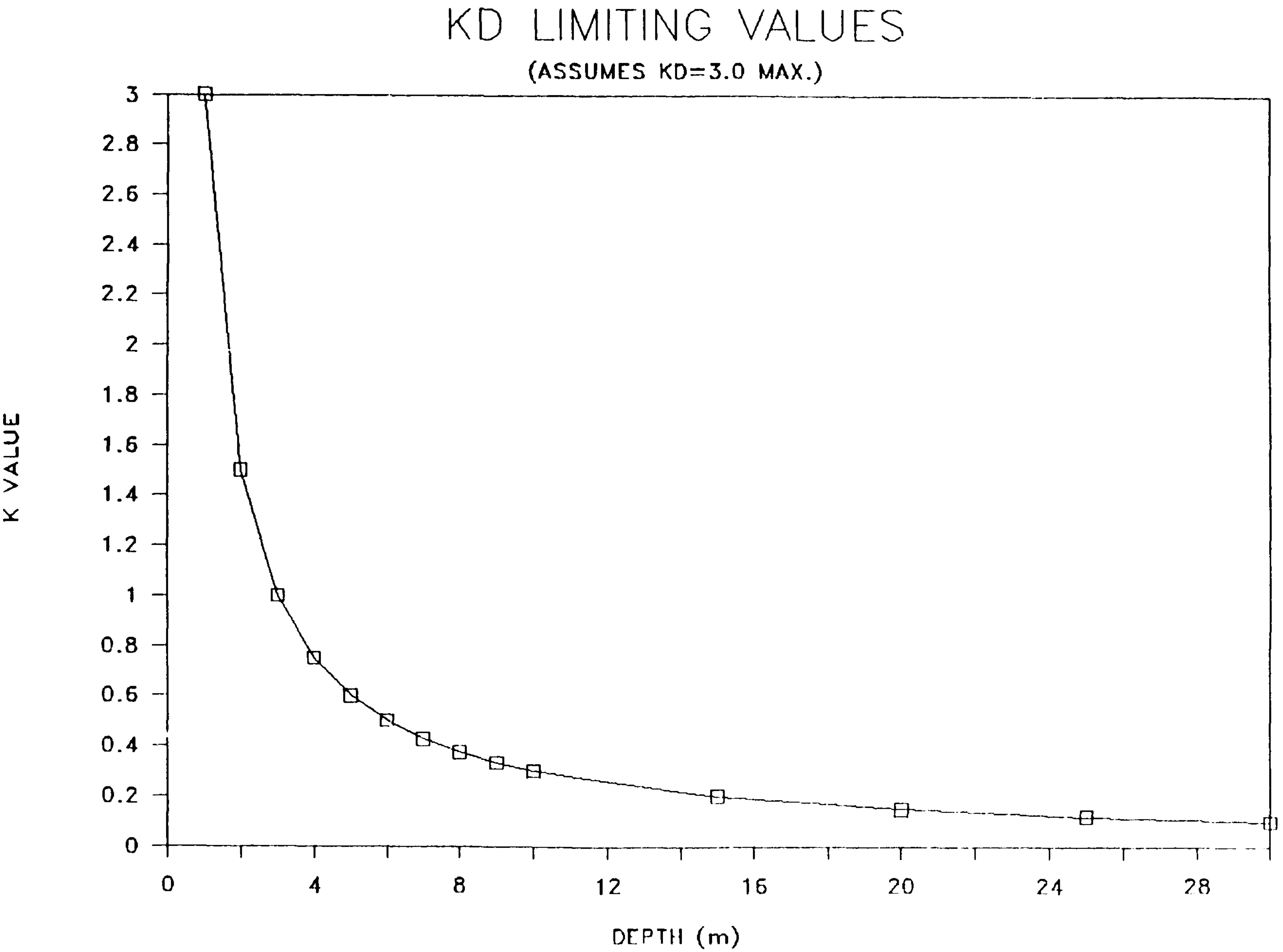

KD LIMITING VALUES
(ASSUMES KD=3.0 MAX.)
K VALUE
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
4
8
12
16
20
24
28
DEPTH (m)

FIG 57

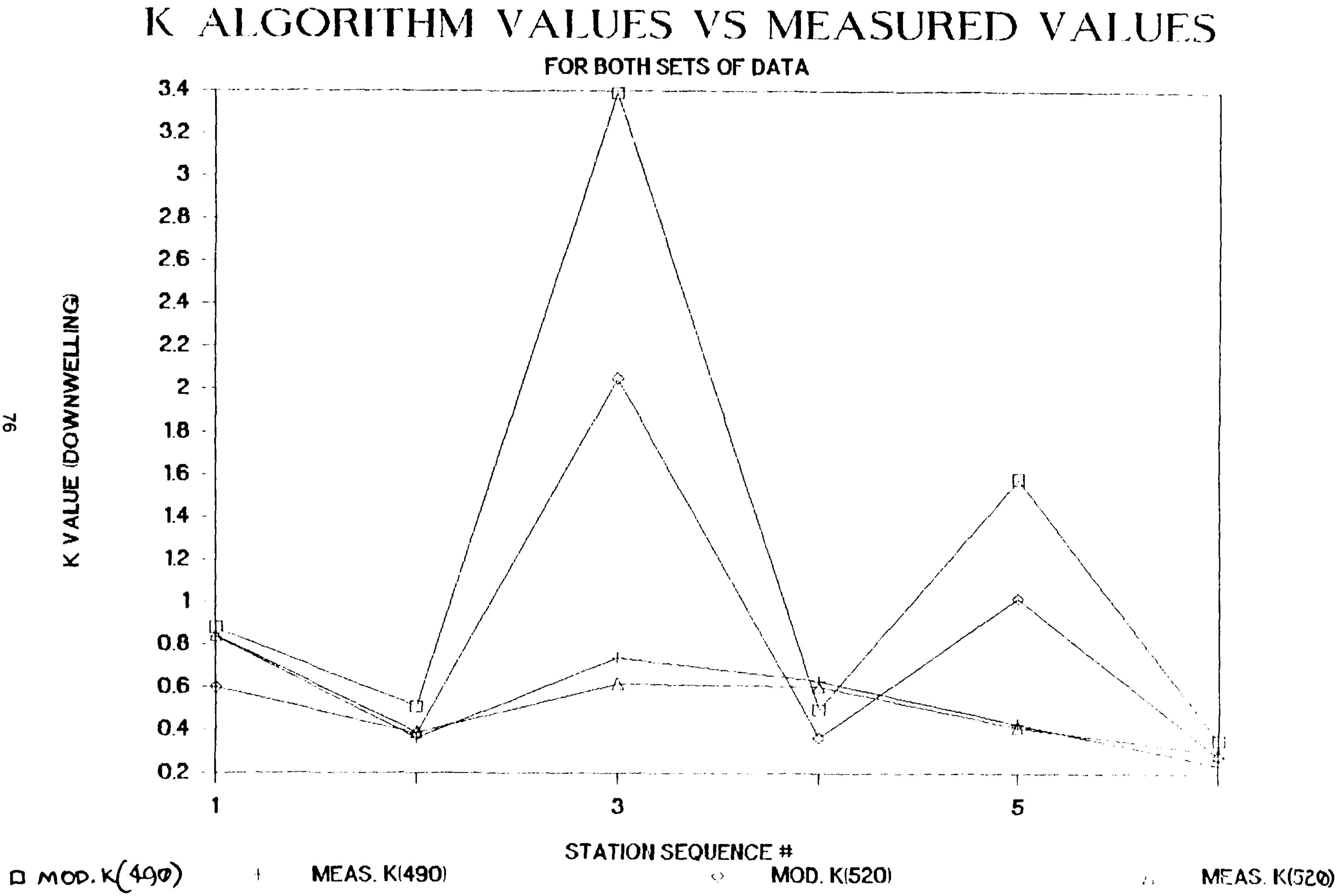

K ALGORITHM VALUES VS MEASURED VALUES
FOR BOTH SETS OF DATA
K VALUE (DOWNWELLING)
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
1
3
5
STATION SEQUENCE #
□ MOD. K(490)
+ MEAS. K(490)
◇ MOD. K(520)
△ MEAS. K(520)

FIG. 58.

TABLES

TABLE 1

STATION #	STATION DISTANCE (FT)	DATE	TIME	DEPTH (m)
1	660	6/18/88	1236	2.2
2	1220	6/18/88	1405	4.2
3	1900	6/18/88	1540	7.5
2	1220	8/17/88	1415	5+
2	1220	8/17/88	1607	5+
3	1900	8/17/88	1123	9+

TABLE 2.

REFLECTOMETER DATA

LOCATION: Duck N.C. DATE: 10/3/88

INSTRUMENT: HUNTER MODEL, S/N: 40D

CALIBRATION STANDARDS: GREEN: 'SPECTRALON' BLUE:

ACTUAL: GREEN: BLUE:

STATION	SAMPLE	REFLECTION %		REMARKS (DRY) SAMPLES
		Gr	Bl.	
N/A	300'	30.8	21.3	FINE RED TO TAN SAND
N/A	500'	29.8	20.6	COARSE TAN SAND (SHELL FRAG.)
~1	700'	25.7	18.8	VERY COARSE TAN/BROWN SAND W/ LARGE SHELL FRAGS.
2	1220'	24.7	18.1	Fine Grey Sand
NA	1600'	25.1	18.4	Fine " Sand
3	1900'	22.5	17.3	VF/SILT DARK GREY SAND

TABLE. 3

REFLECTOMETER DATA

LOCATION: DUCK, N.C. DATE: 10/3/88

INSTRUMENT: HUNTER MODEL, S/N: 40D

CALIBRATION SPECTRALON

STANDARDS: ~~GREEN: BLUE:~~

ACTUAL: ~~GREEN: BLUE:~~

STATION	SAMPLE	REFLECTION %		REMARKS (Wet) Samples
		Grn	Blu.	
N/A	300'	13.5	7.25	See previous sheet
N/A	500'	12.5	6.9	of dry samples
~1	700'	12.1	6.8	for sediment des-
2	1220'	9.1	5.8	cription.
NA	1600'	9.4	6.0	
3	1900'	7.0	4.9	

APPENDICES

APPENDIX A

APPENDIX A

The following are extractions from " A USER'S GUIDE TO THE COASTAL ENGINEERING RESEARCH CENTER'S (CERC'S) FIELD RESEARCH FACILITY" by W. A. Birkemeier et al. A companion volume is SUMMARY OF ARCHIVED ATLANTIC COAST WAVE INFORMATION STUDY PRESSURE, WIND, WAVE, AND WATER LEVEL DATA by R. M. Brooks and W. D. Corson will also be a source of information presented in this section.

The documentation pages from both reports will be included herein.

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER Instruction Report CERC-85-1	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A USER'S GUIDE TO THE COASTAL ENGINEERING RESEARCH CENTER'S (CERC'S) FIELD RESEARCH FACILITY		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) William A. Birkemeier, H. Carl Miller, Stanton D. Wilhelm, Allen E. DeWall, and Carol S. Gorbics		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Coastal Engineering Research Center PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE May 1985 13. NUMBER OF PAGES 136
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Duck, N. C.
Field Research Facility--CERC
User's guide

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Coastal Engineering Research Center's (CERC's) Field Research Facility (FRF) at Duck, N. C., is a 561-m-(1,840-ft-)long pier and laboratory dedicated to basic and applied coastal research. This report, which describes the facility, the instrumentation and data being collected, and the local area, is designed to be used as an aid in planning experiments to be conducted at the facility. Use of the FRF by coastal researchers is encouraged.

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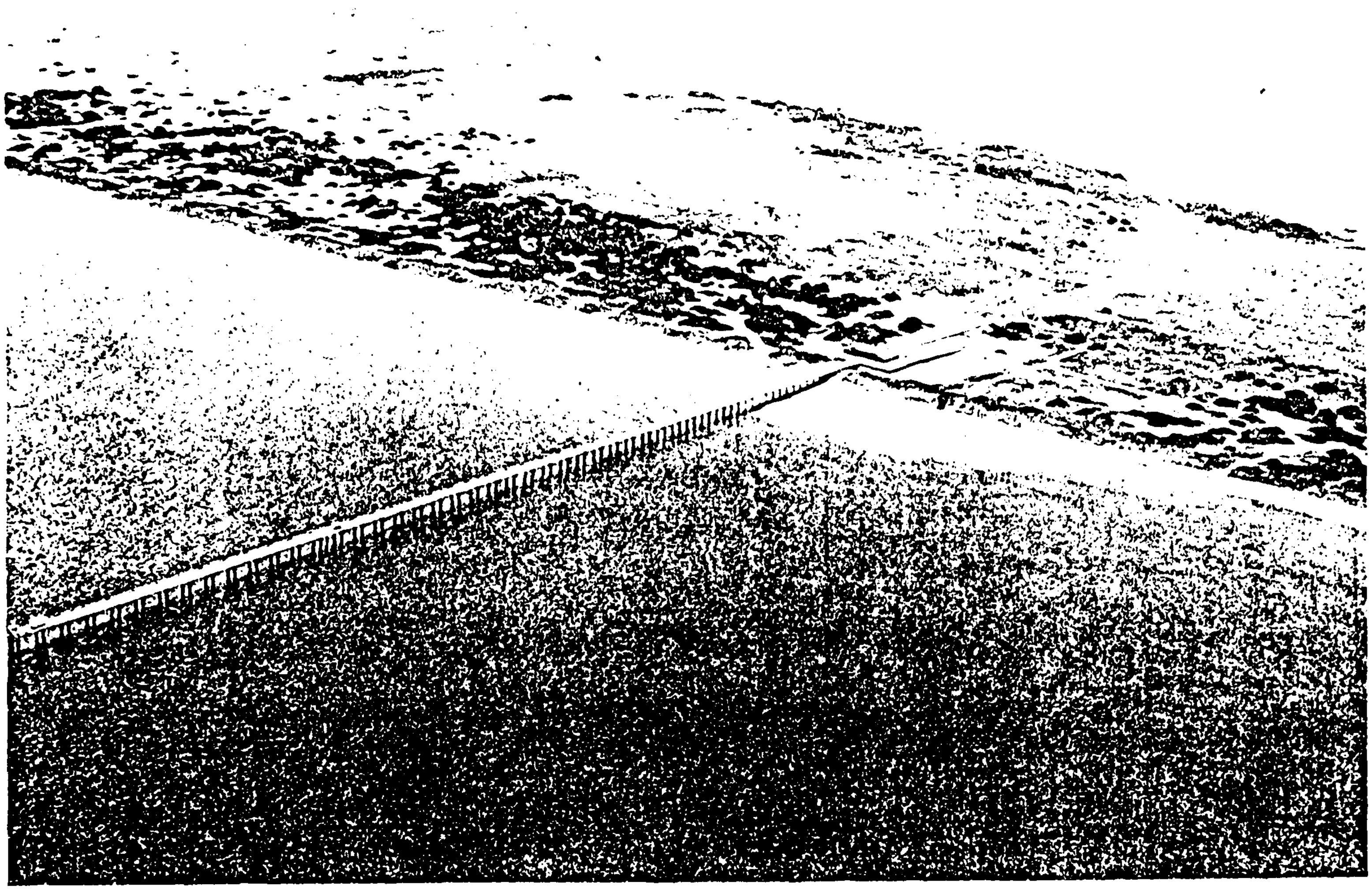
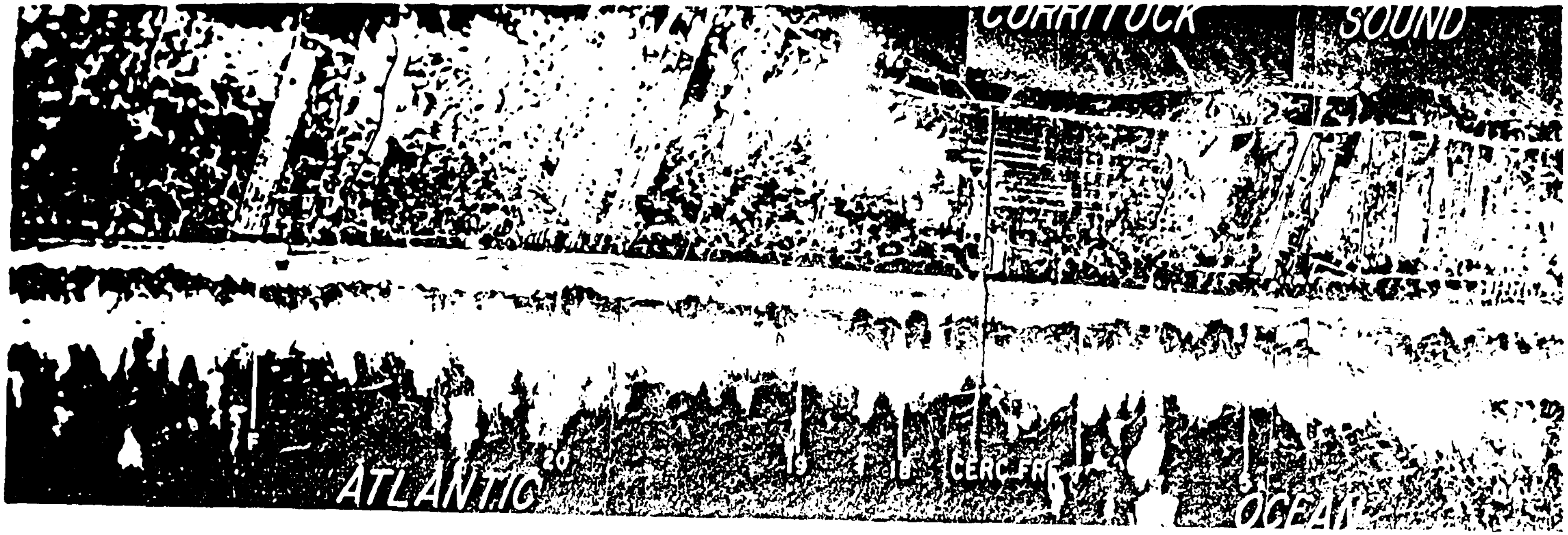
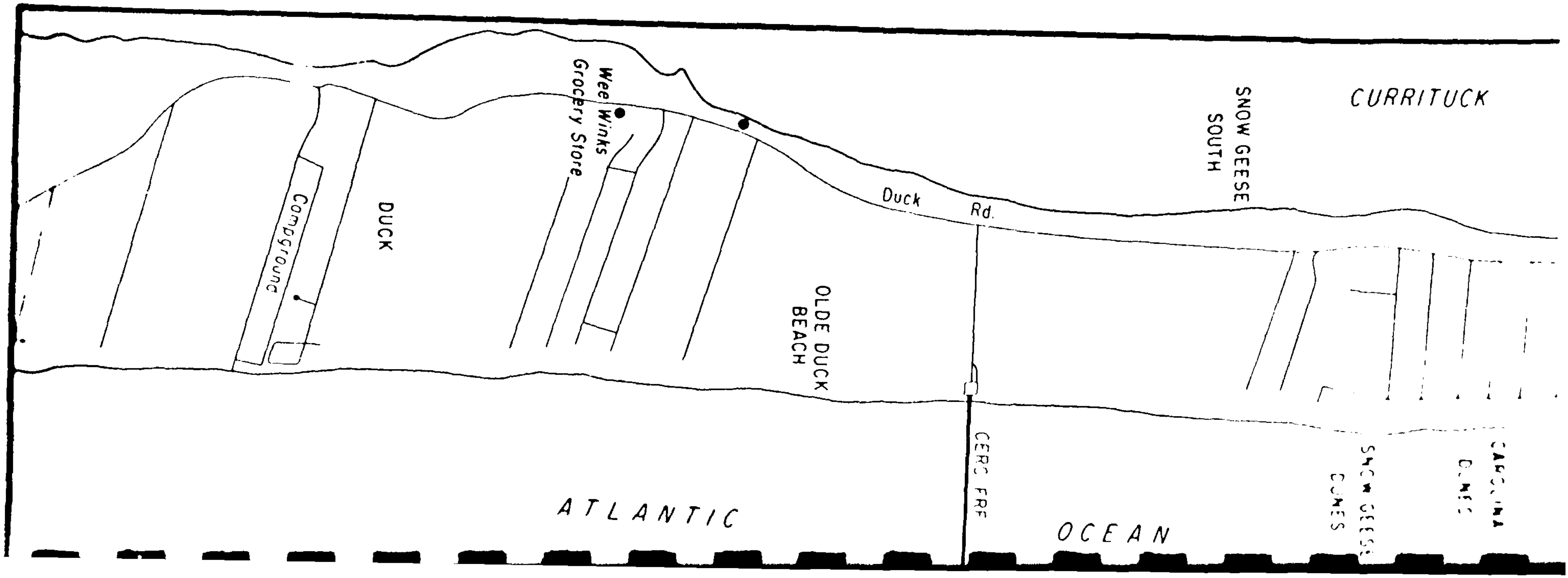
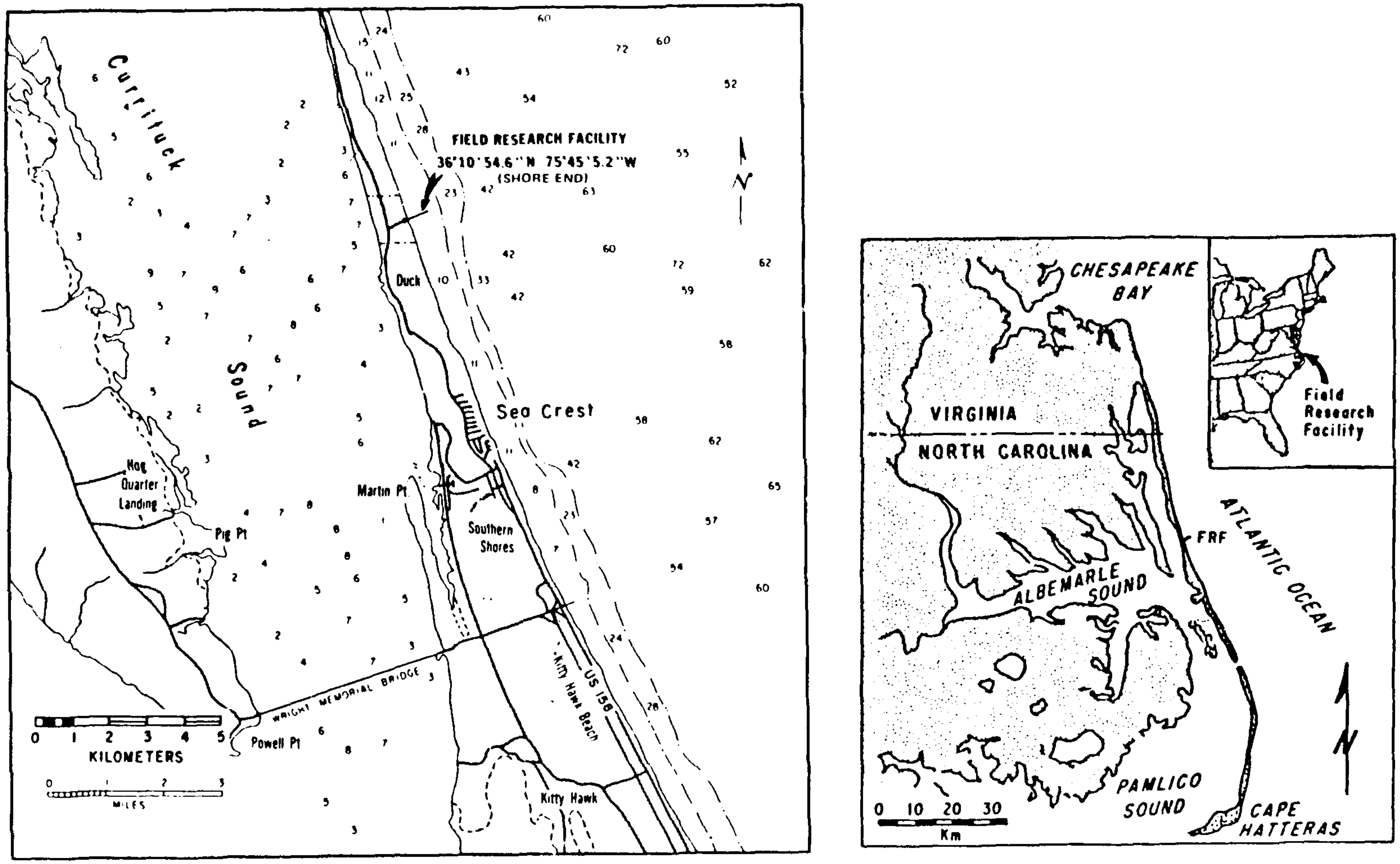


CERC's FRF

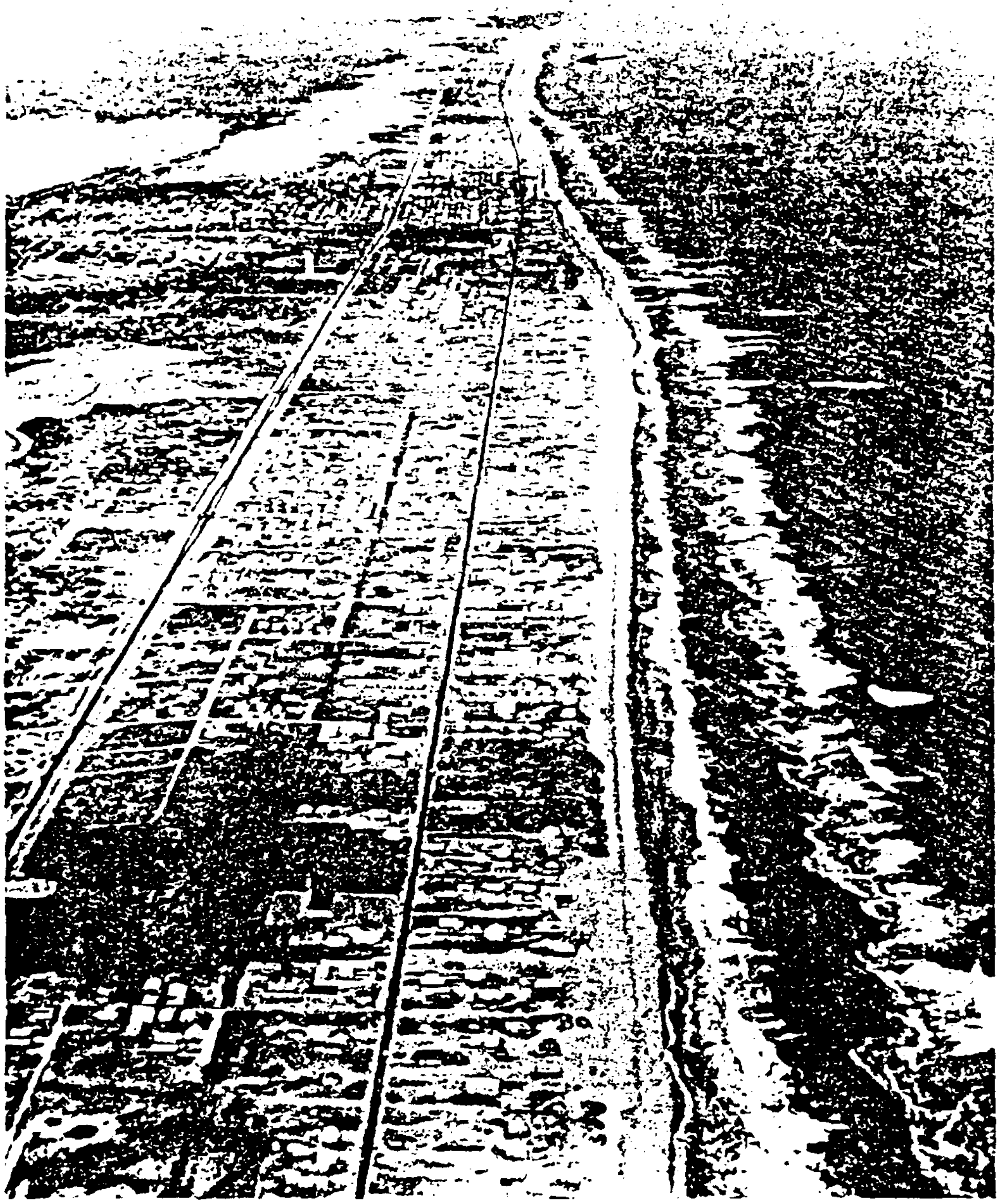


Aerial mosaic of FRF pier site

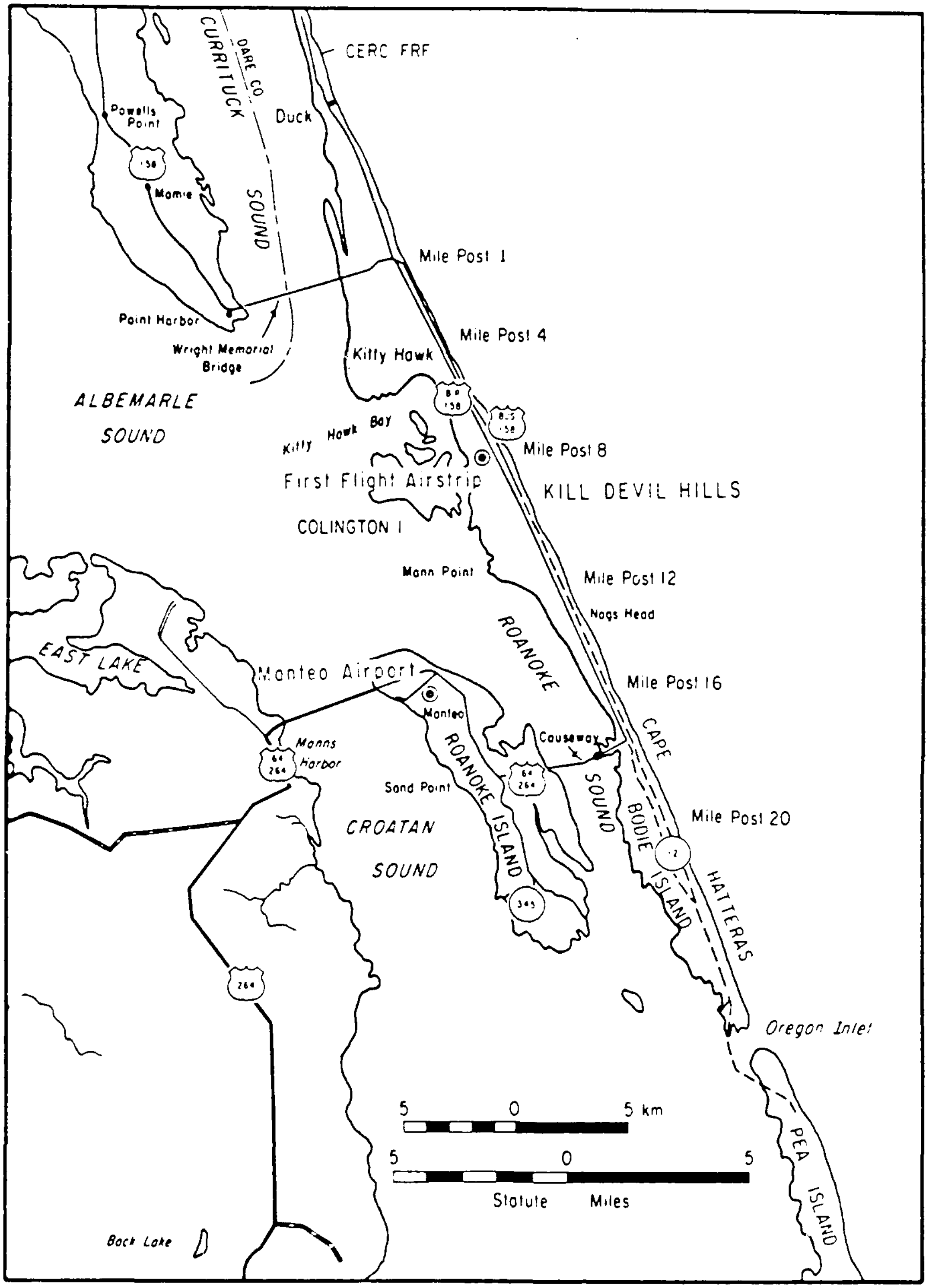




Location of the FRF



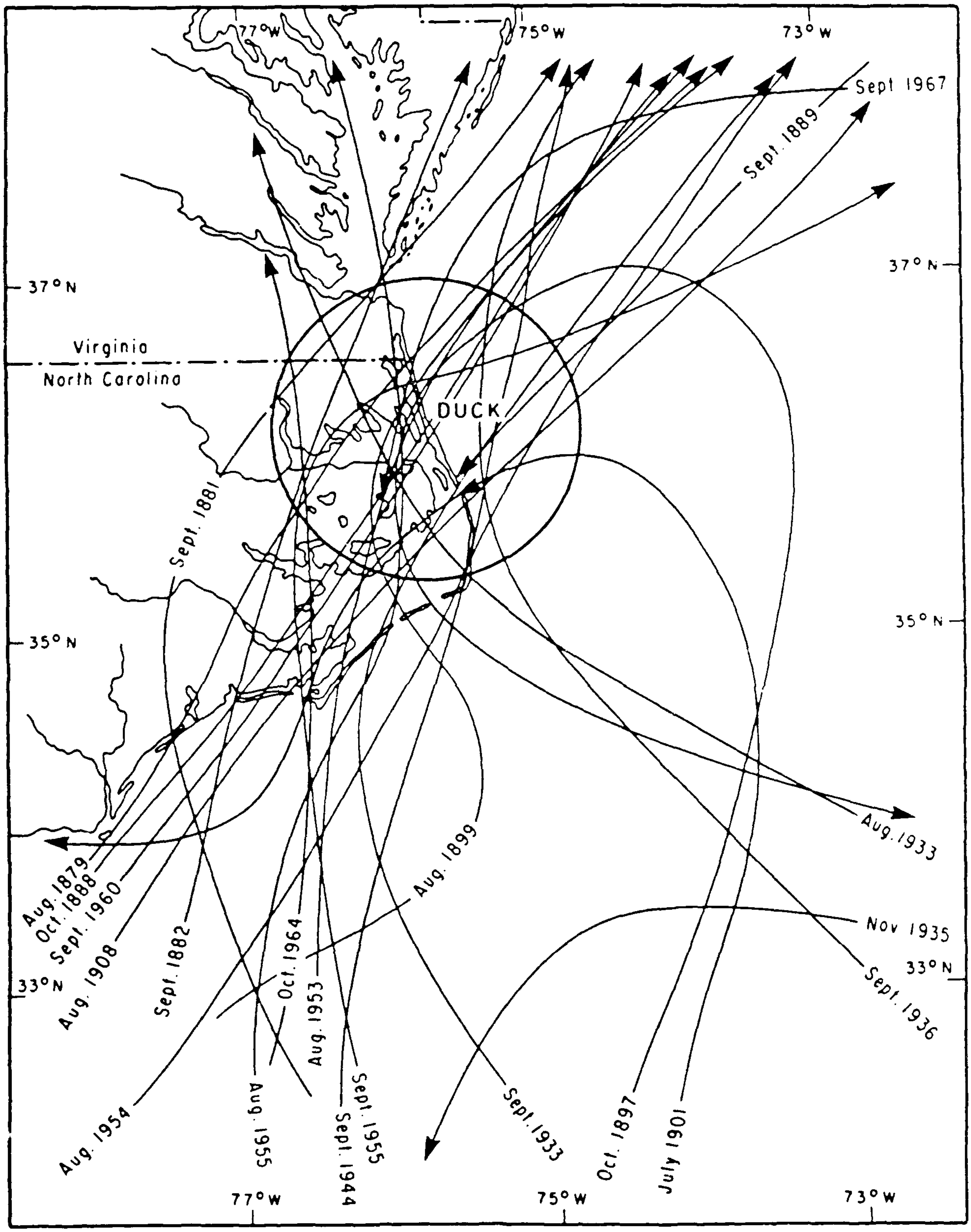
Aerial view looking north from Kill Devil Hills, showing three distinct longshore bars



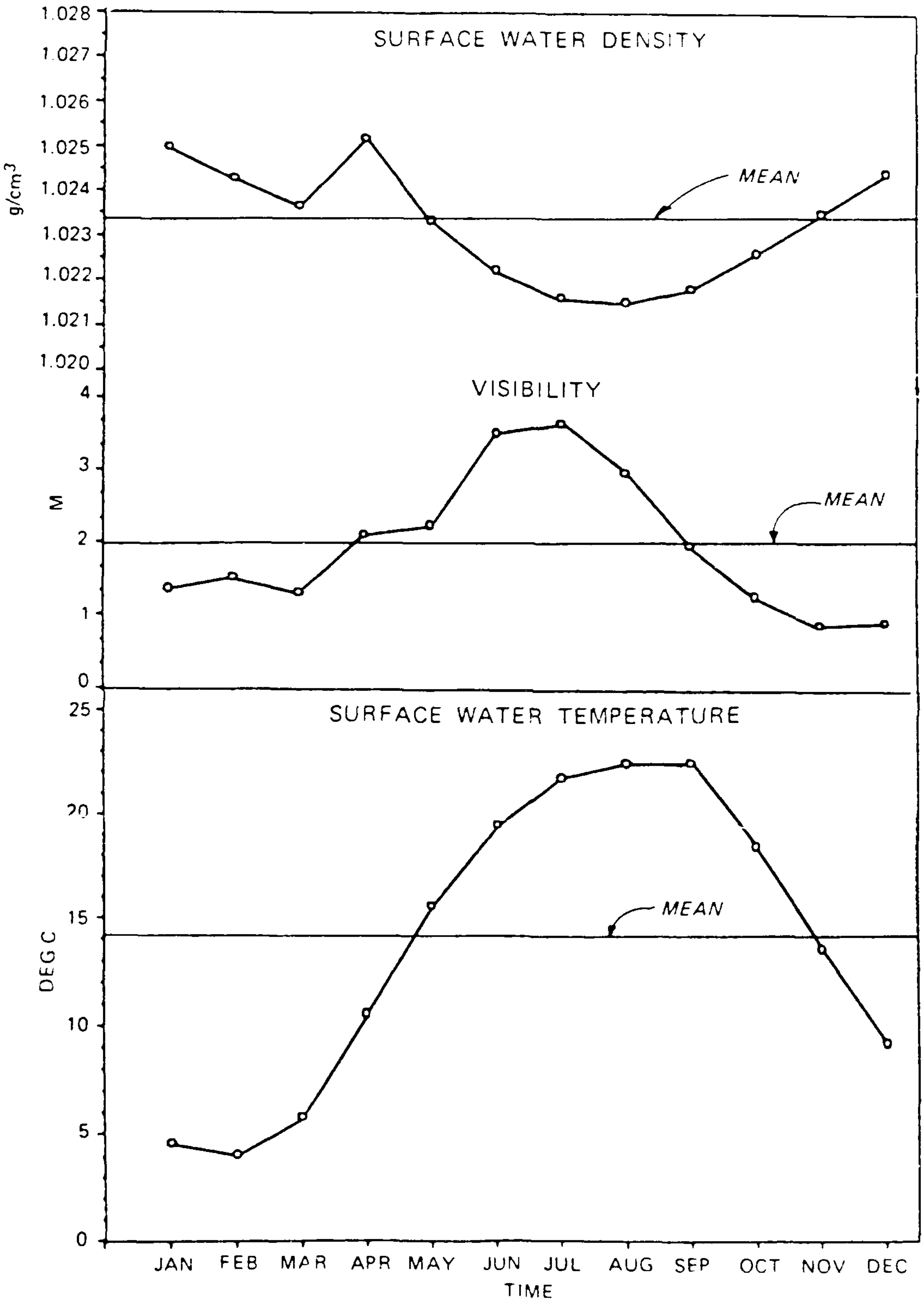
Map of local area*

---

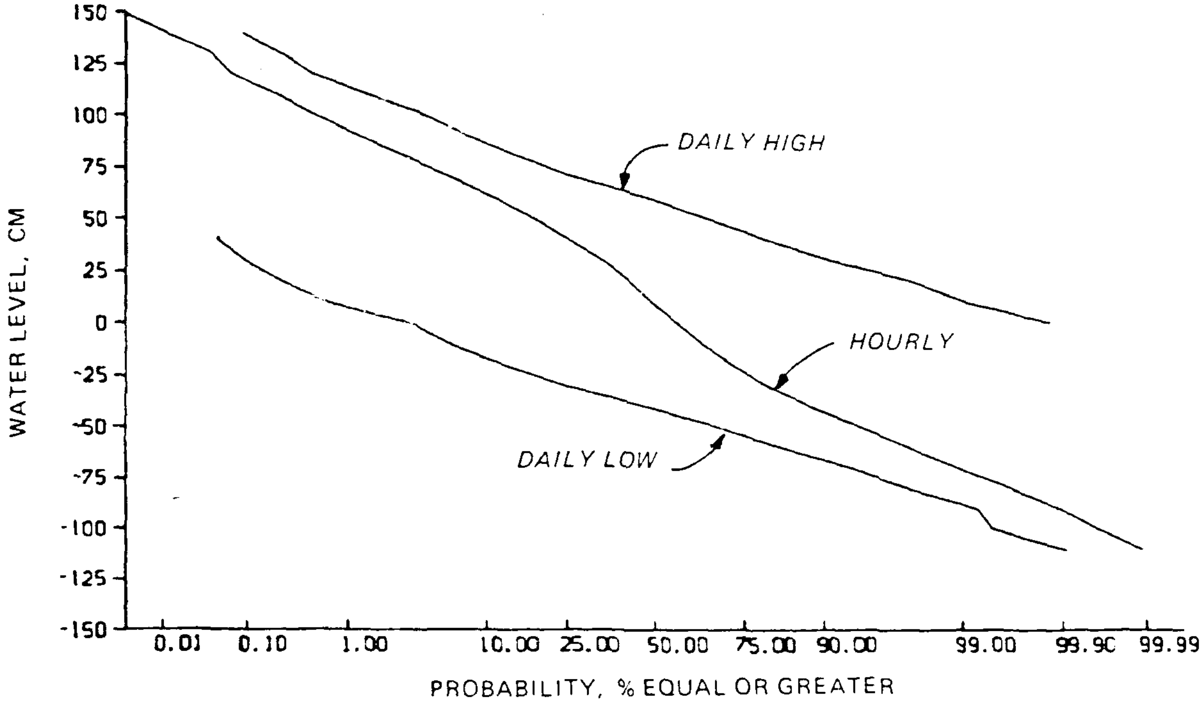
* Modified from United States Geological Survey (USGS) maps NJ 18-8, -11; 18-2.



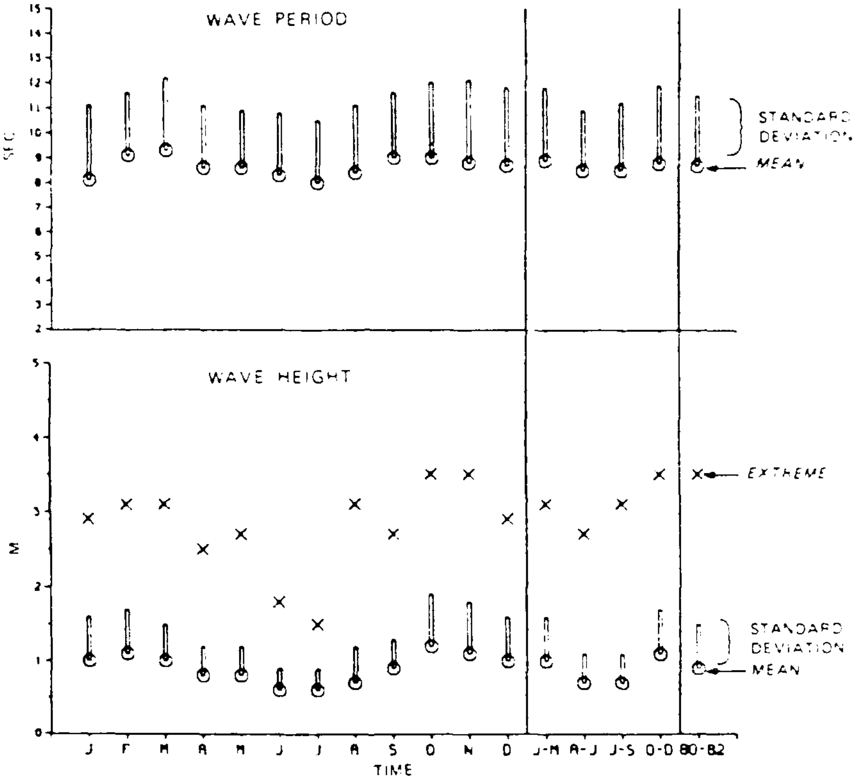
Major hurricanes passing within 90 km (50 nautical miles) of FRF (adapted from Ho and Tracey 1975)



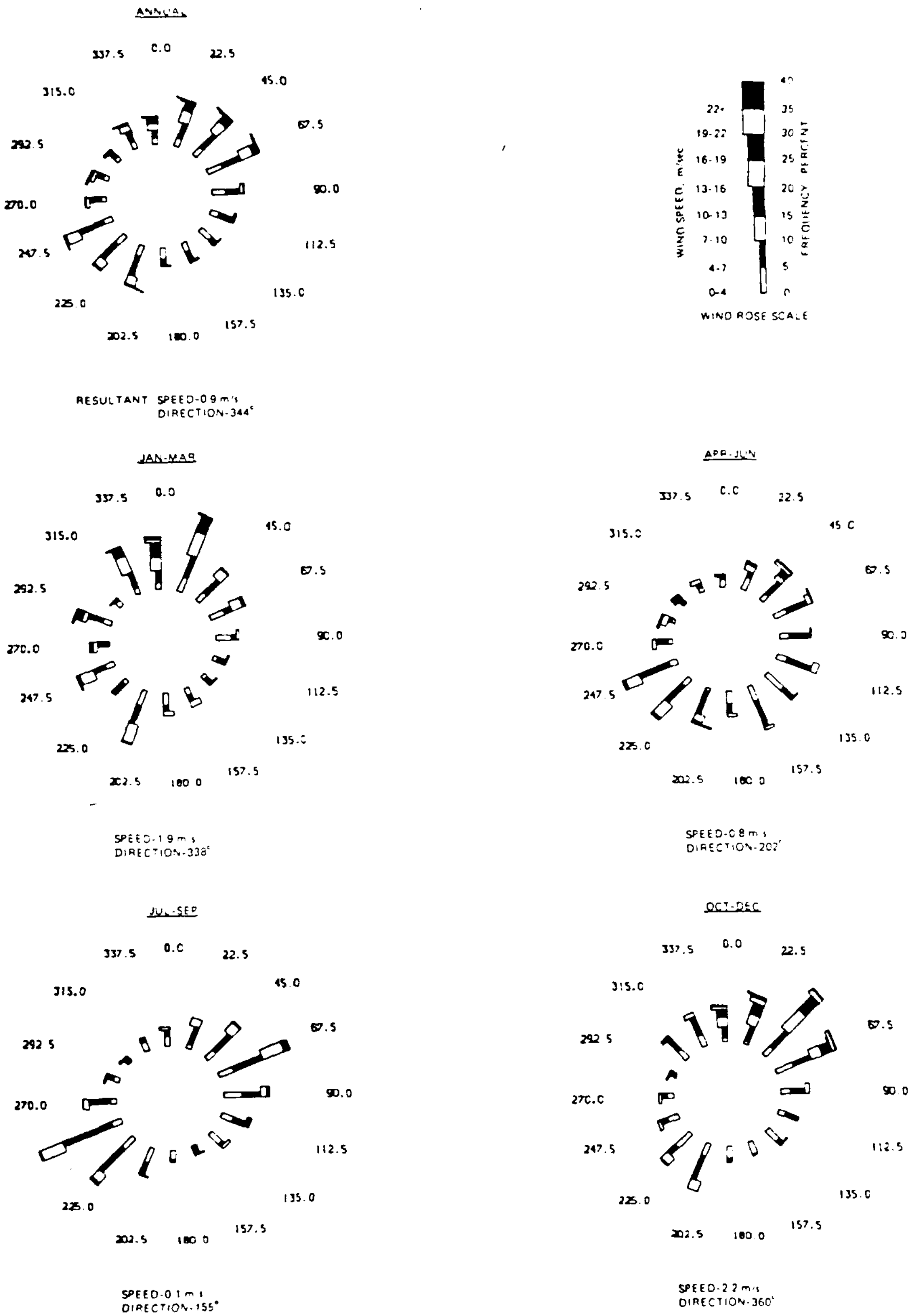
Variation in monthly mean water density, visibility, and temperature, 1980-1982



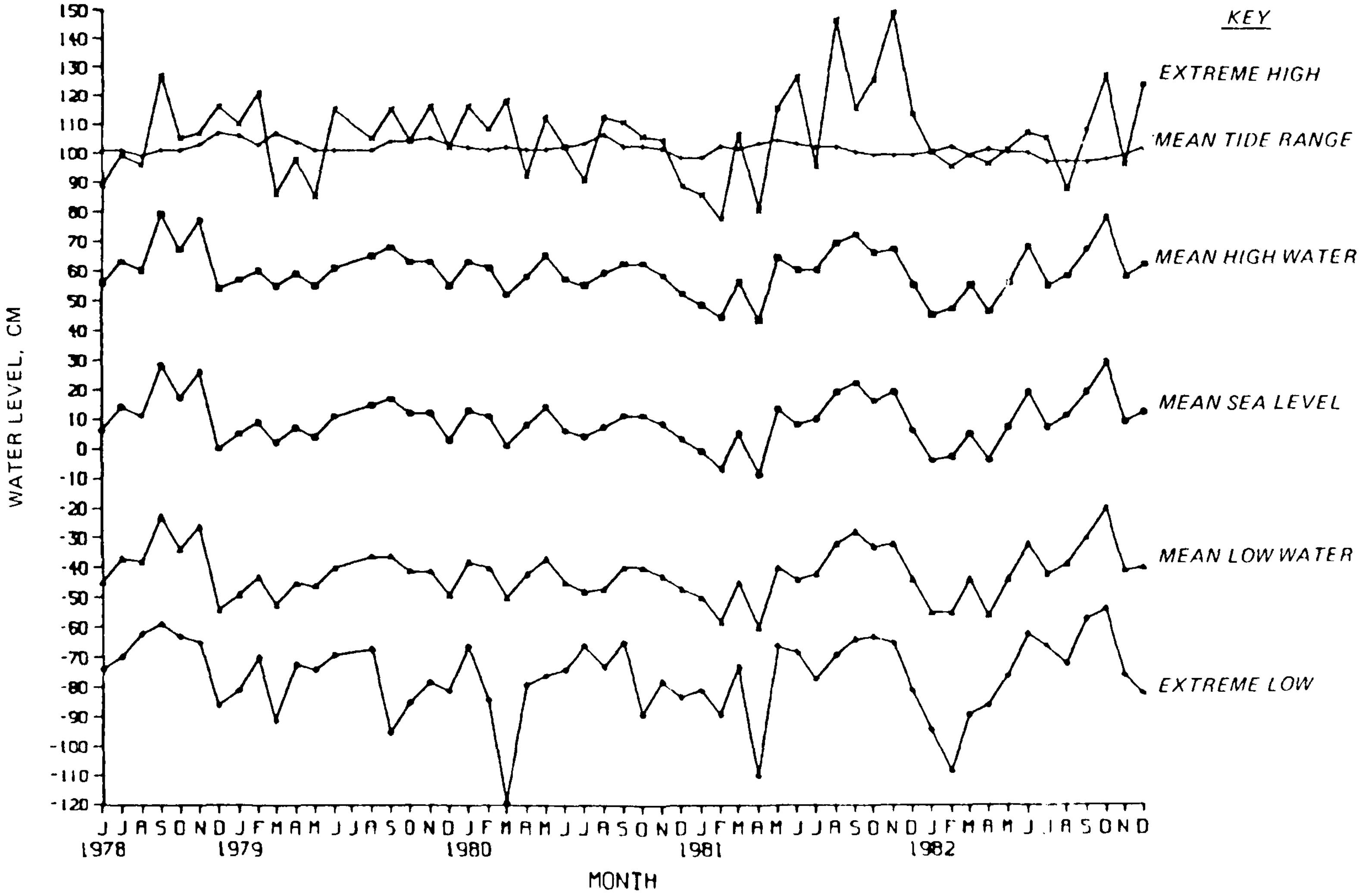
Cumulative distribution of water levels, 1980-1982



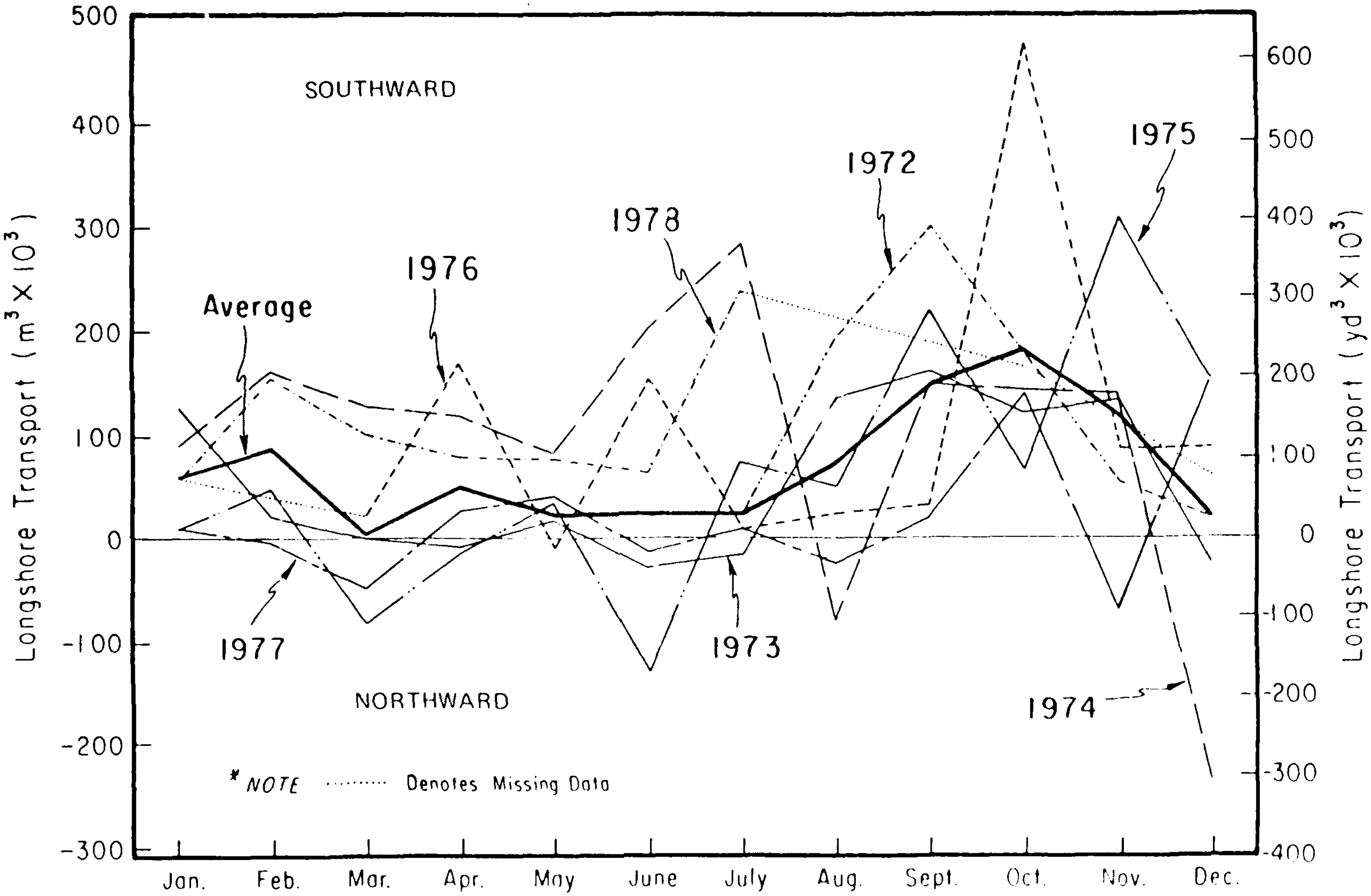
Monthly variation in mean significant wave height and mean peak spectral period (from gage 625 at seaward end of FRF pier, 1980-1982)



Annual and seasonal wind roses for the FRF, 1980 to 1982 (directions are given relative to true north)



Monthly variation in water levels between 1978 and 1982



Monthly means of potential net transport versus time, based on visual wave observations at Sea Crest, N. C. (k = 1.0)

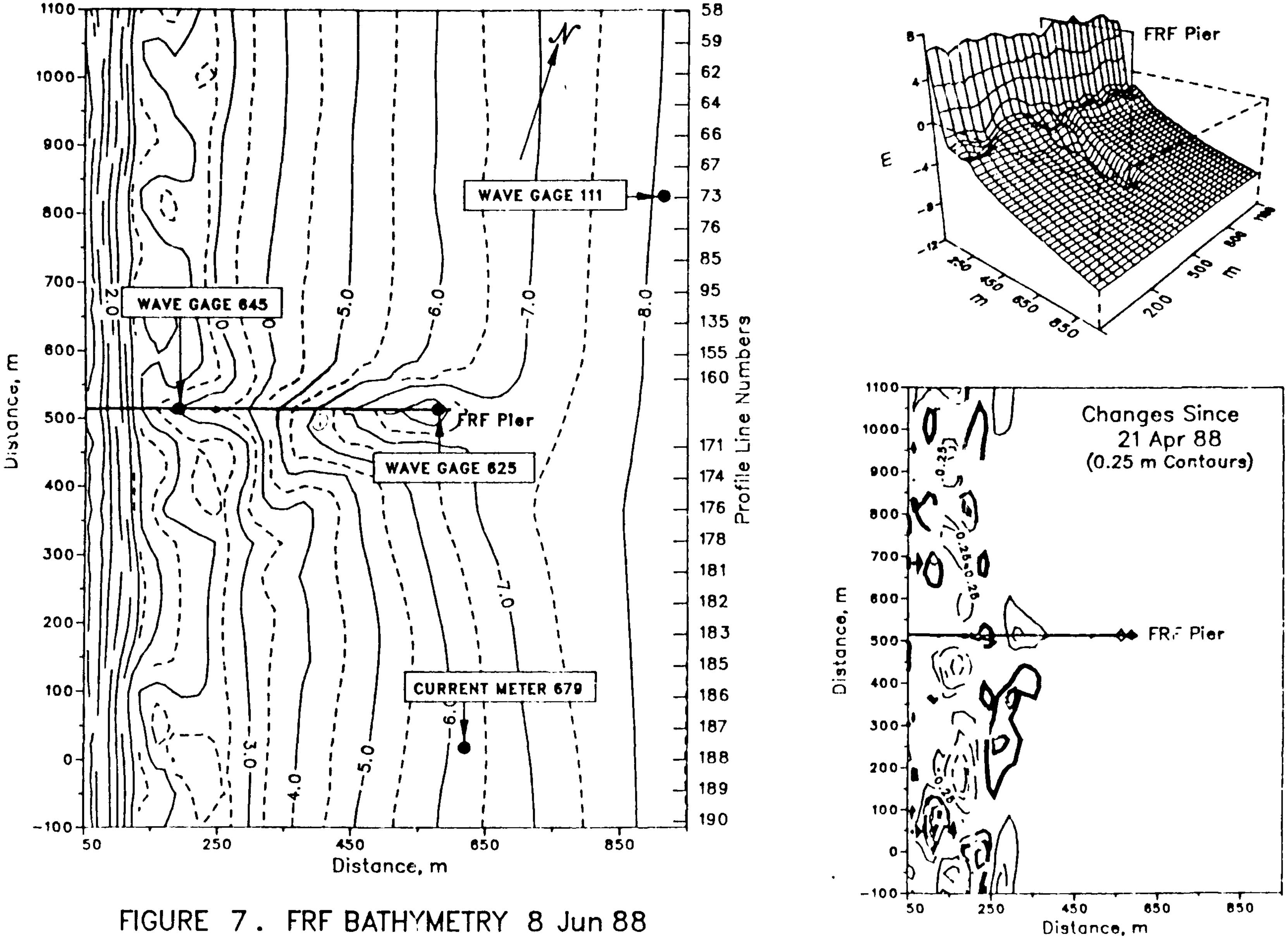


FIGURE 7. FRF BATHYMETRY 8 Jun 88
(Depths Relative to NGVD)

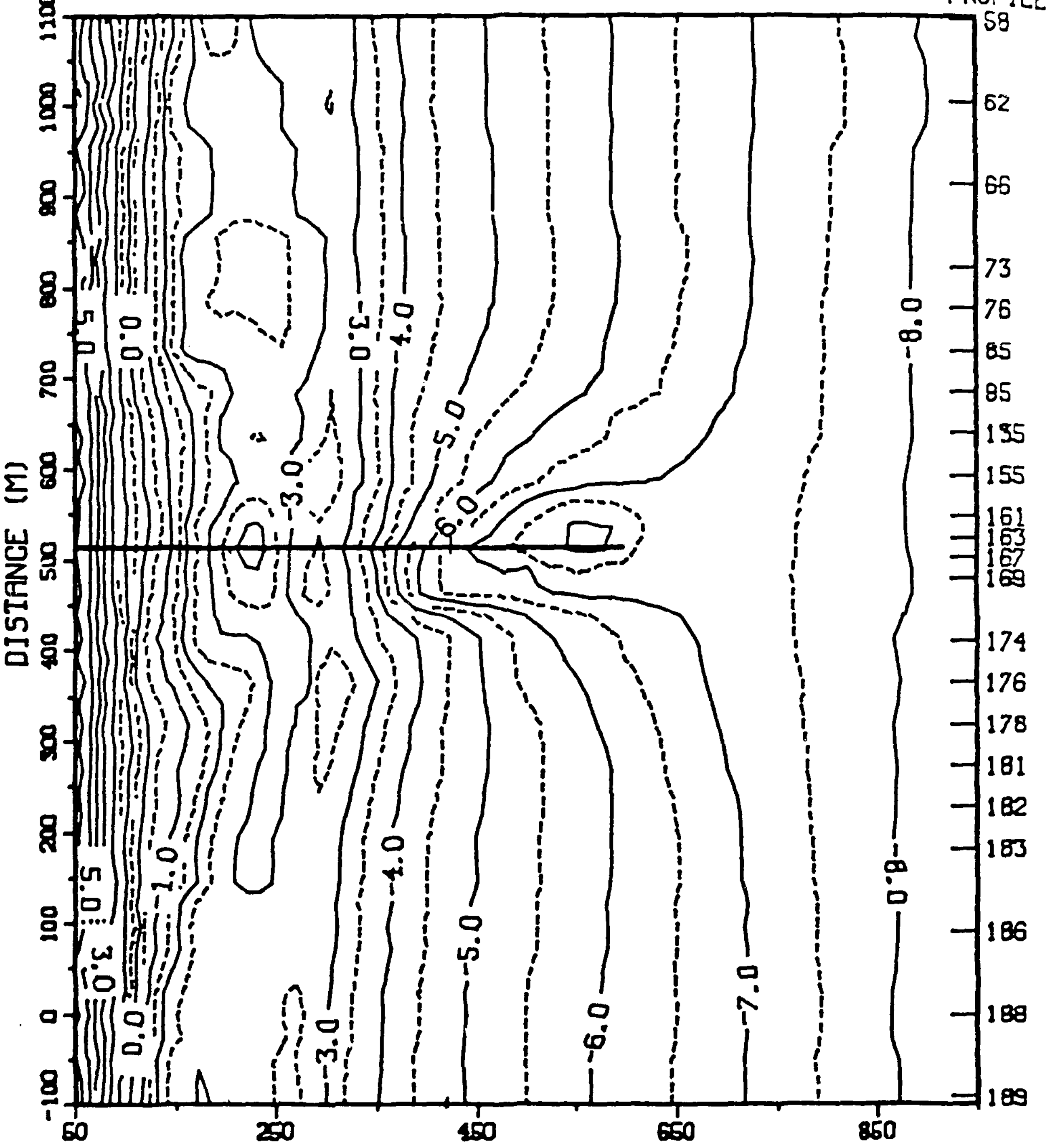


Figure 31. FRF bathymetry, 3 November 1981

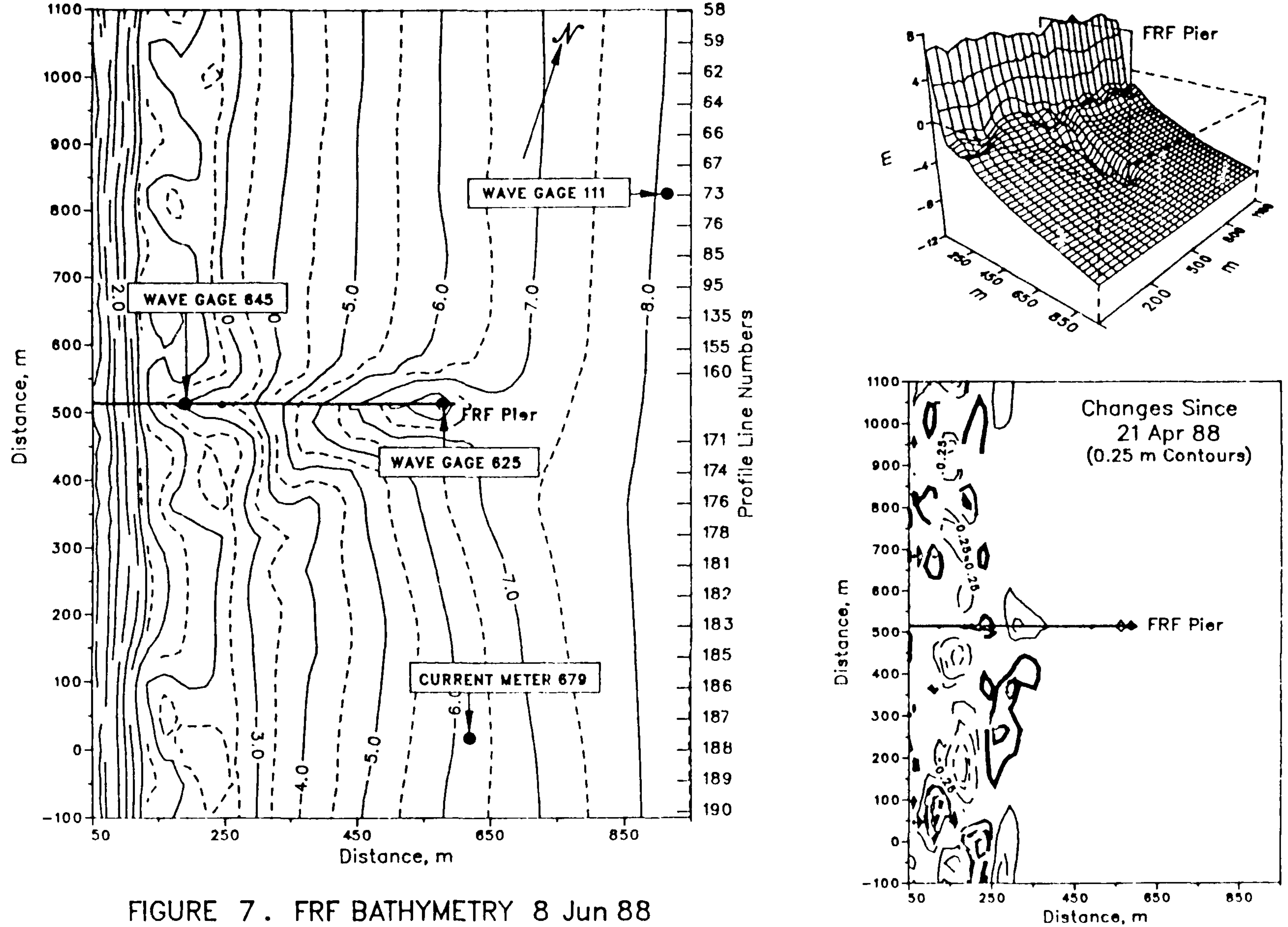
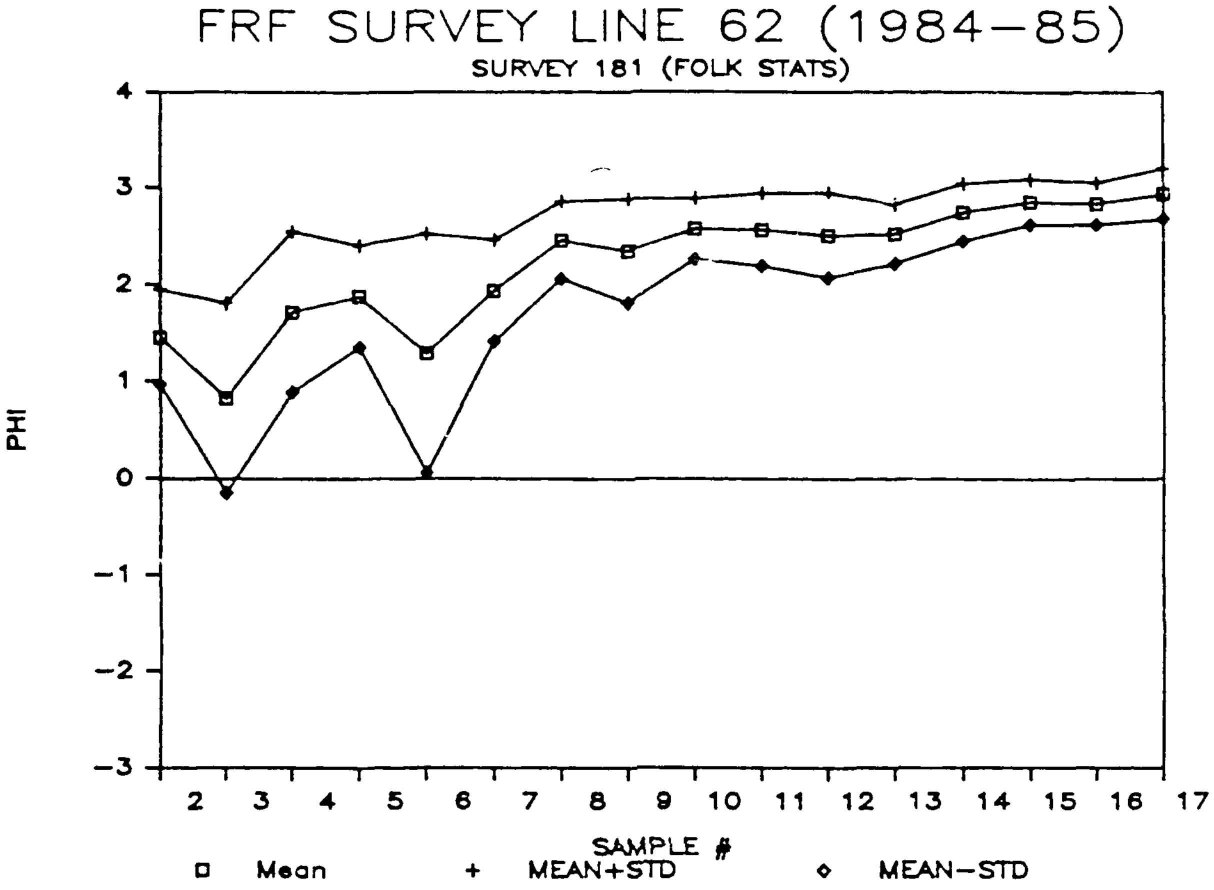
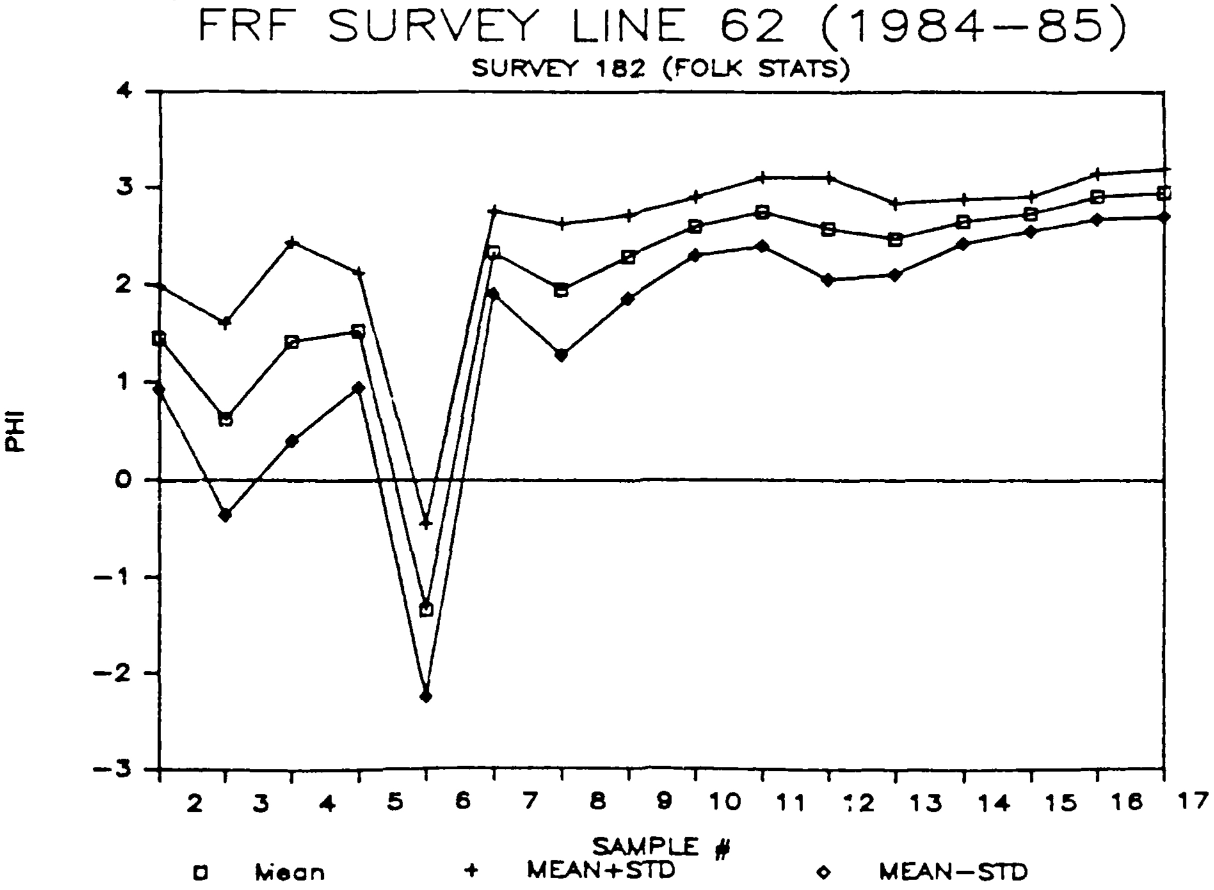
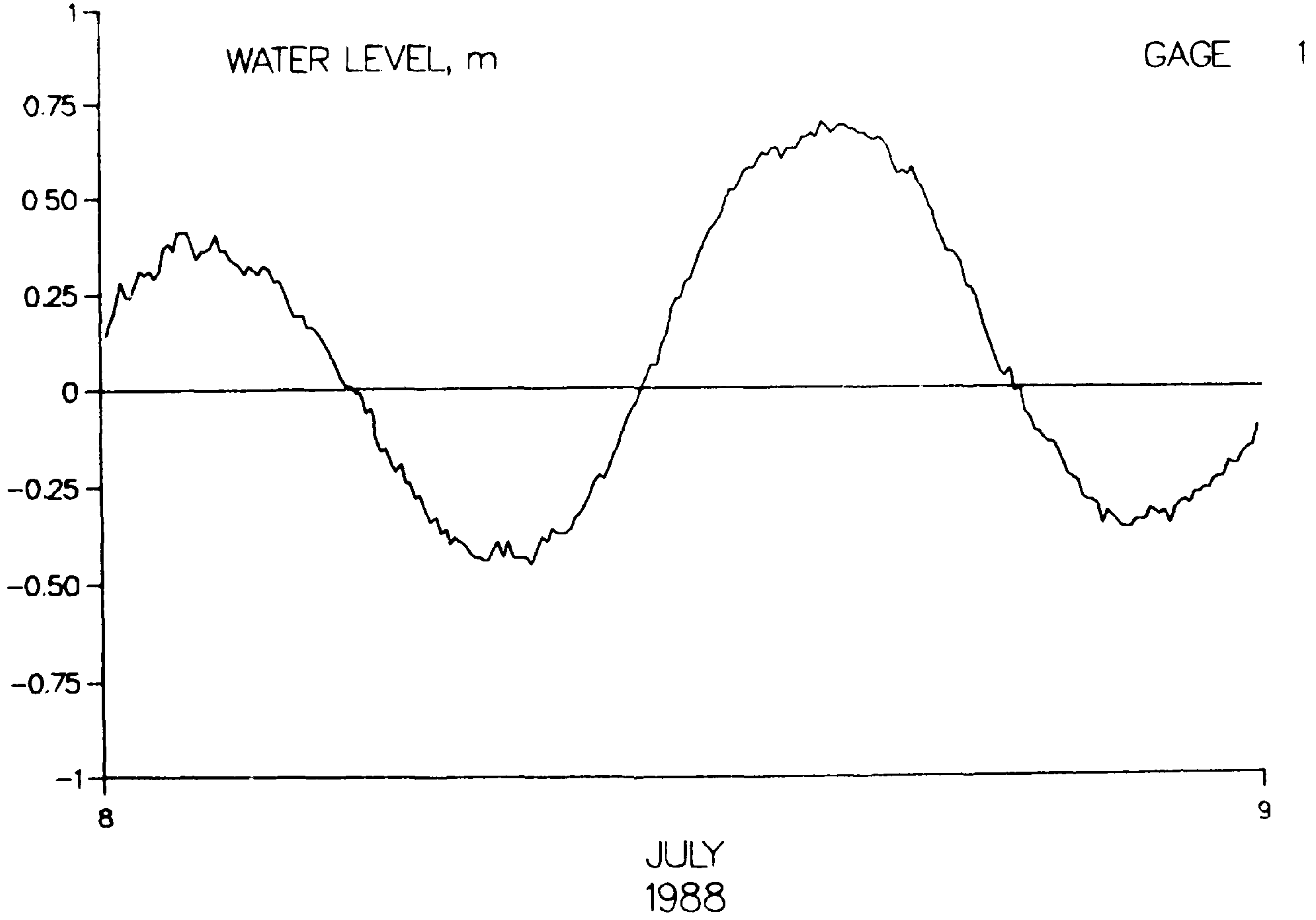


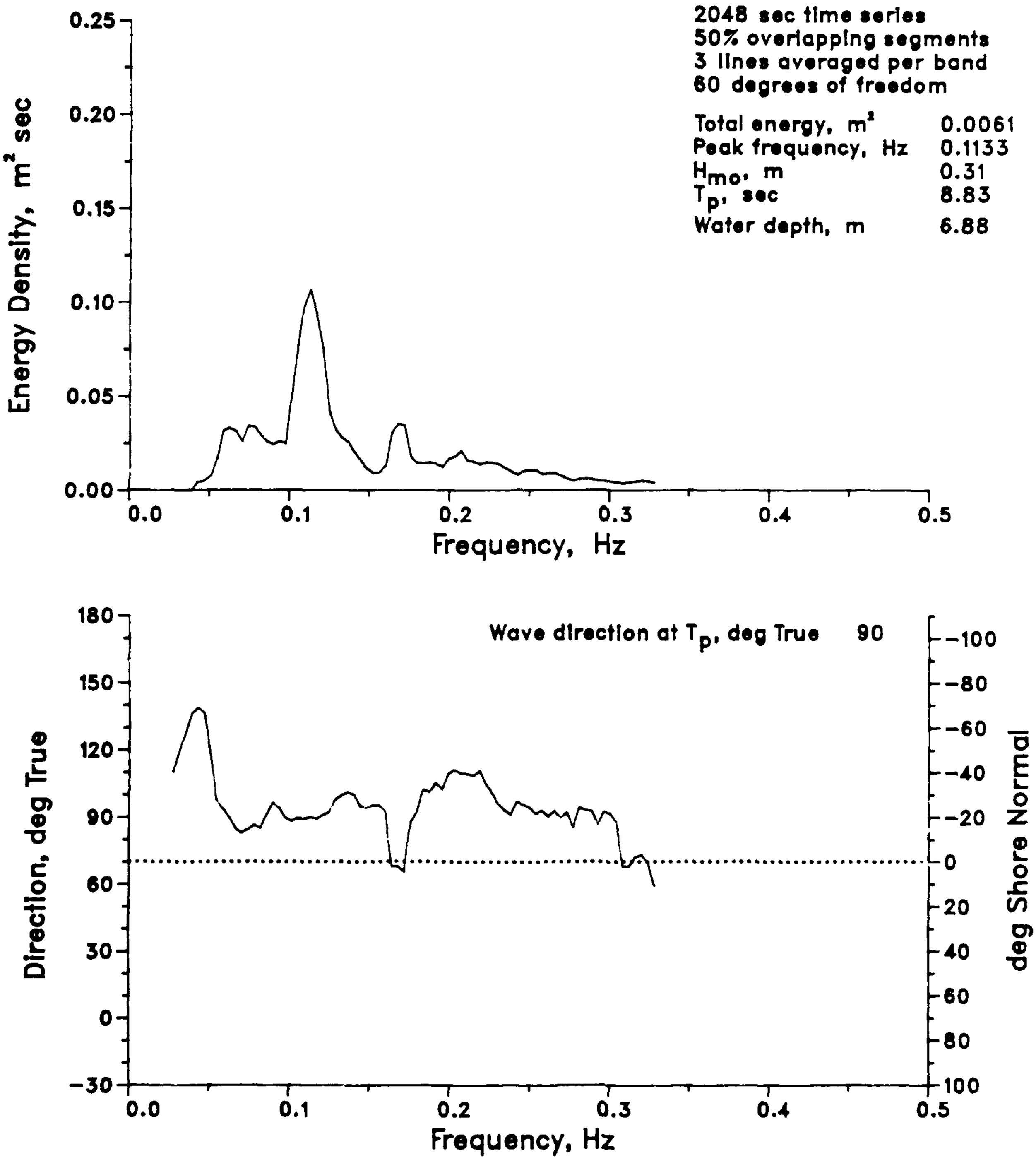
FIGURE 7. FRF BATHYMETRY 8 Jun 88
(Depths Relative to NGVD)


FRF SURVEY LINE 62 (1984–85)
SURVEY 181 (FOLK STATS)
PHI
4
3
2
1
0
−1
−2
−3
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
SAMPLE #
□ Mean
+ MEAN+STD
◇ MEAN–STD

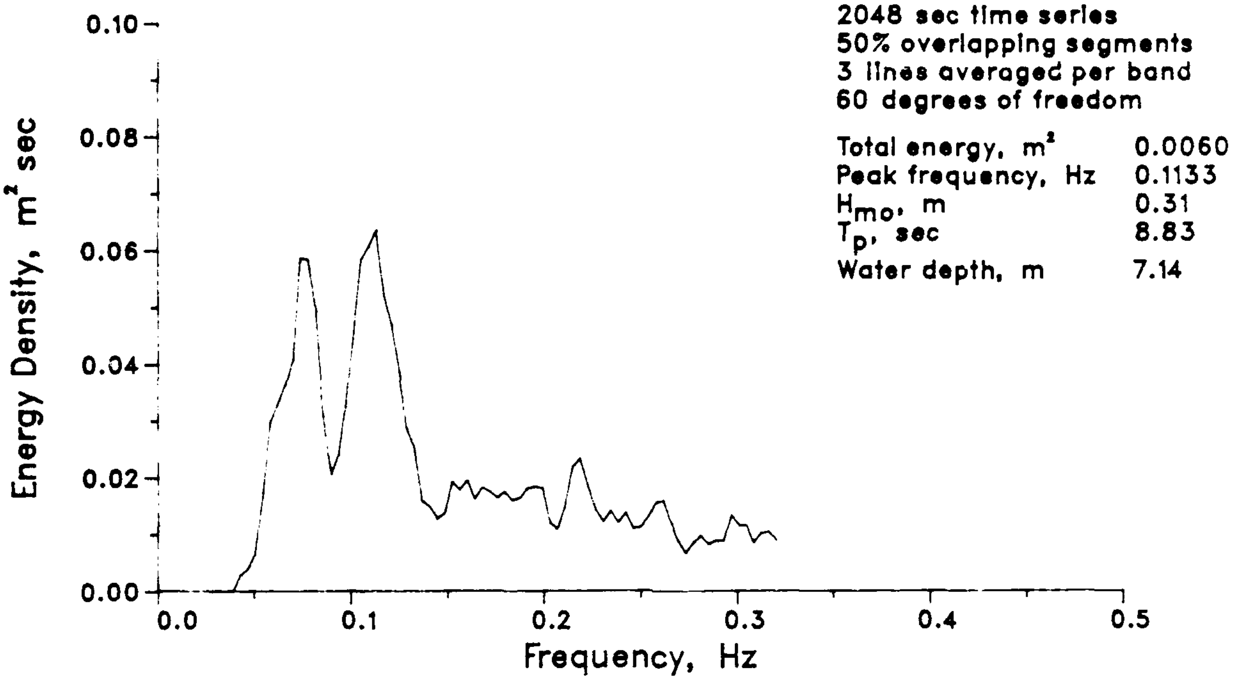

FRF SURVEY LINE 62 (1984–85)
SURVEY 182 (FOLK STATS)
PHI
4
3
2
1
0
−1
−2
−3
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
SAMPLE #
□ Mean
+ MEAN+STD
◇ MEAN–STD

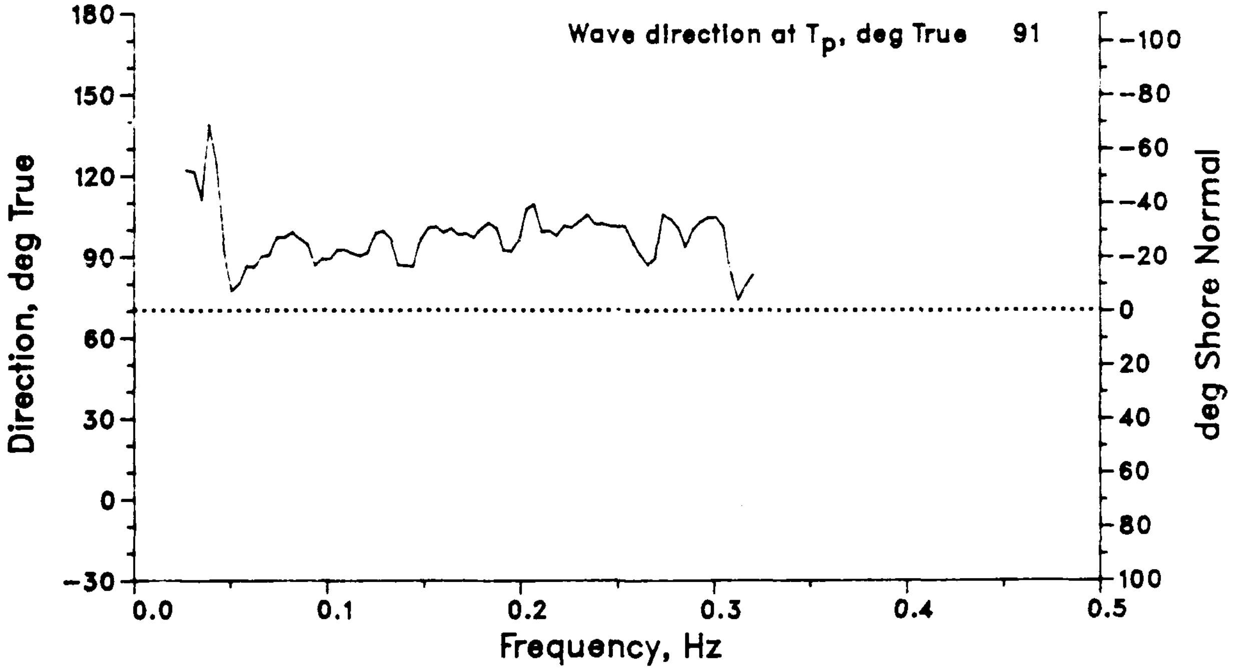

WATER LEVEL, m
GAGE 1
1
0.75
0 50
0.25
0
−0.25
−0.50
−0.75
−1
8
9
JULY
1988

DIRECTIONAL SPECTRUM
PUV at SOUTH TRIPOD
17 AUG 1988 at 1442 EST

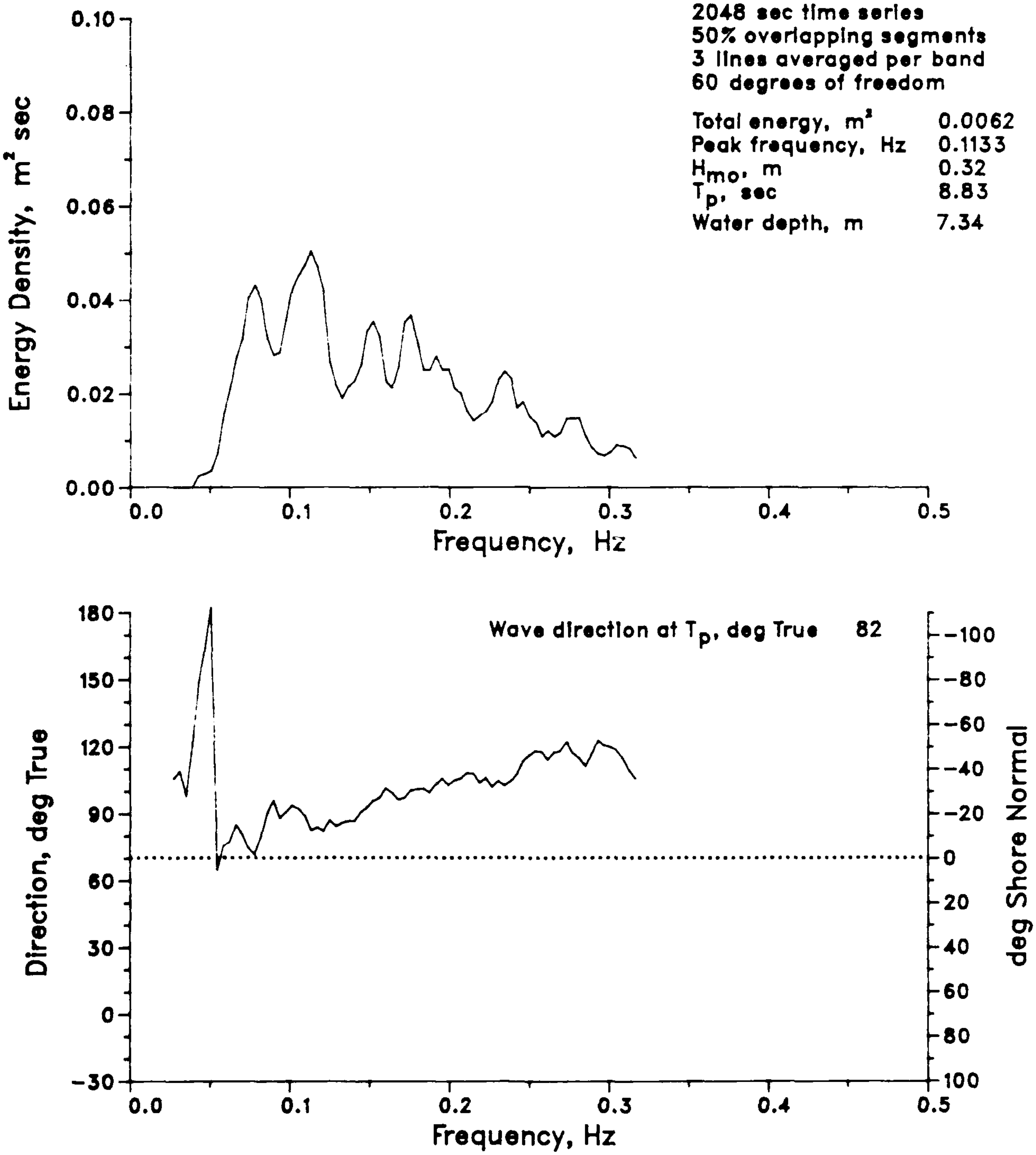


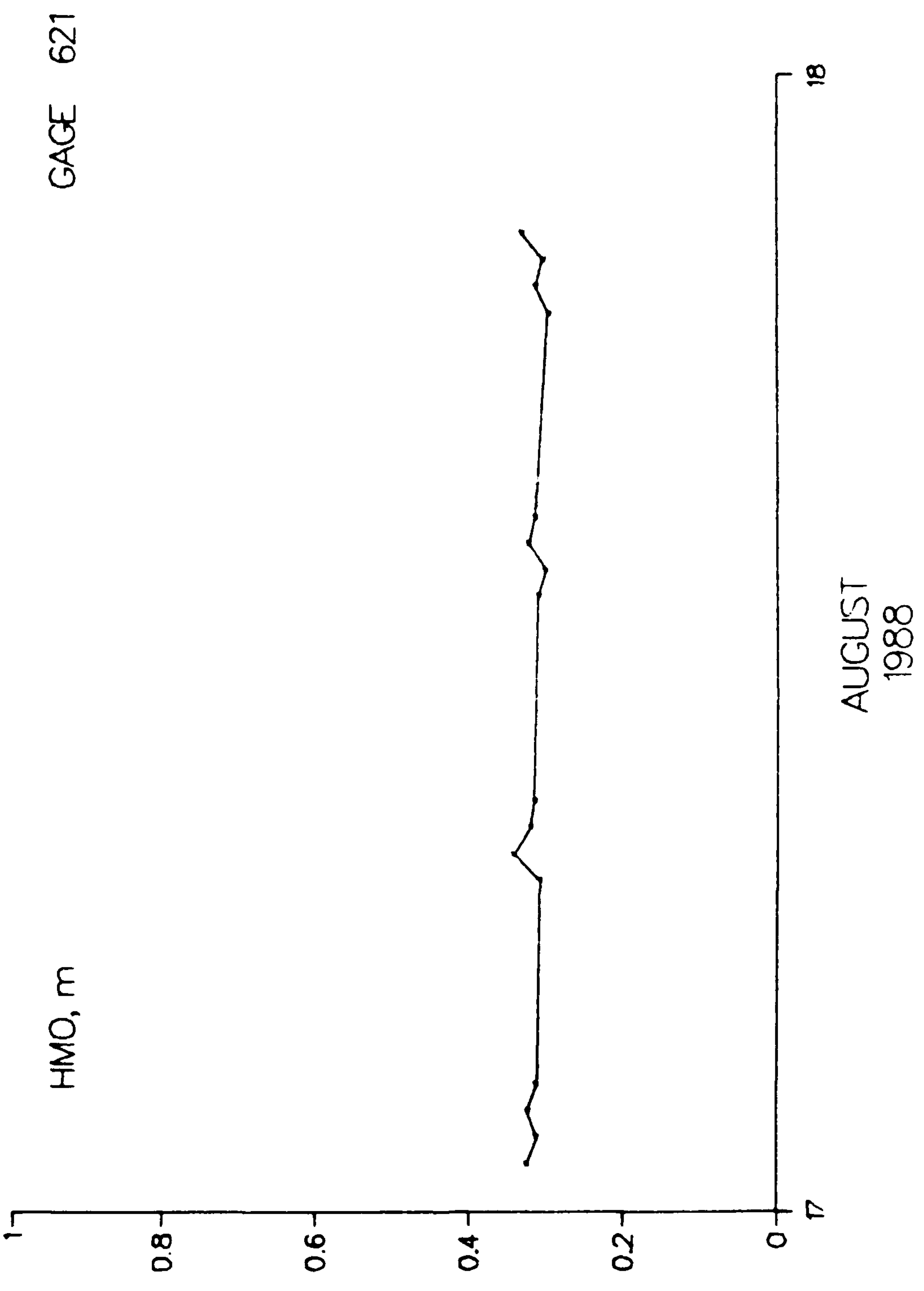
DIRECTIONAL SPECTRUM
PUV at SOUTH TRIPOD
17 AUG 1988 at 1300 EST

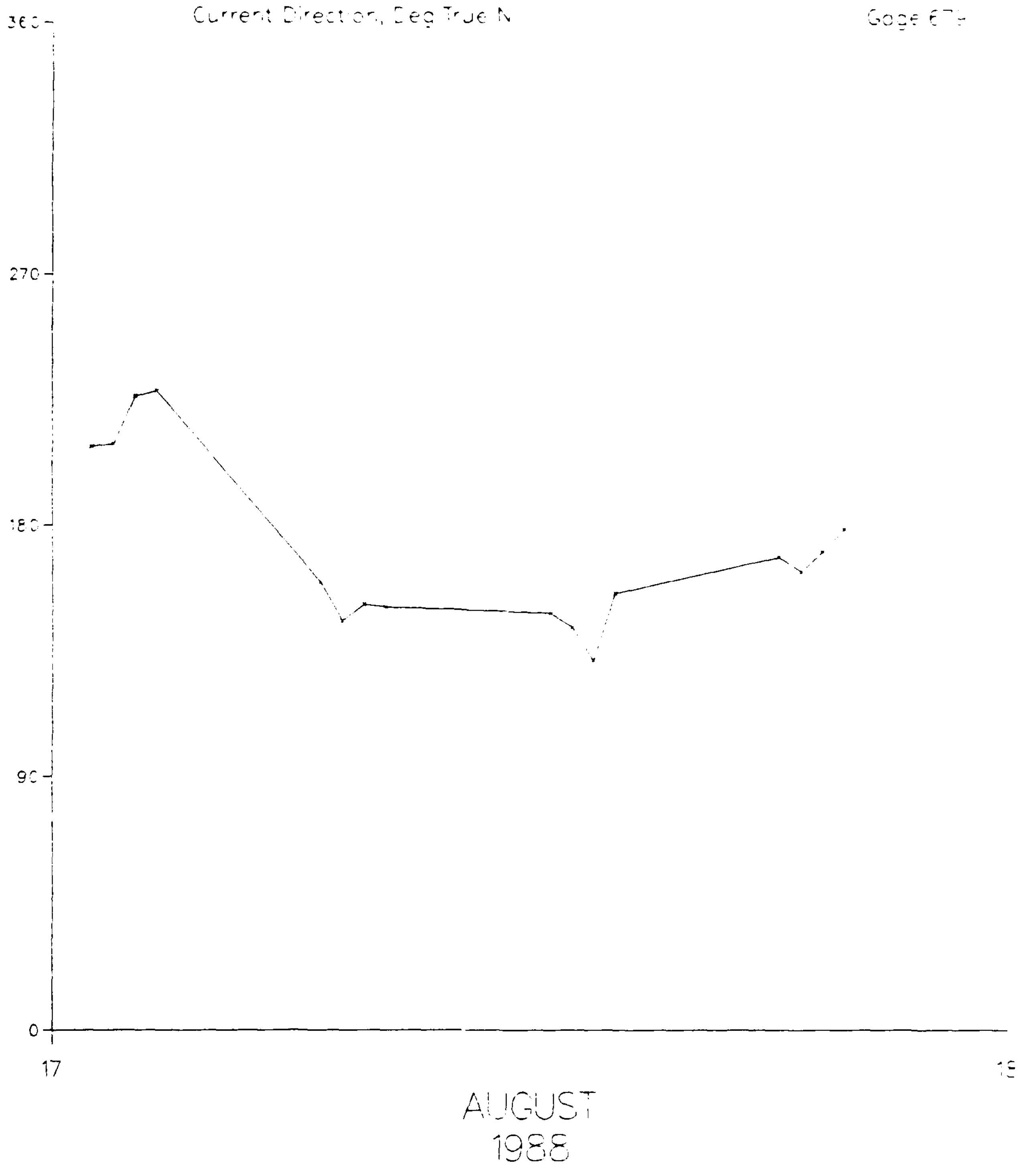


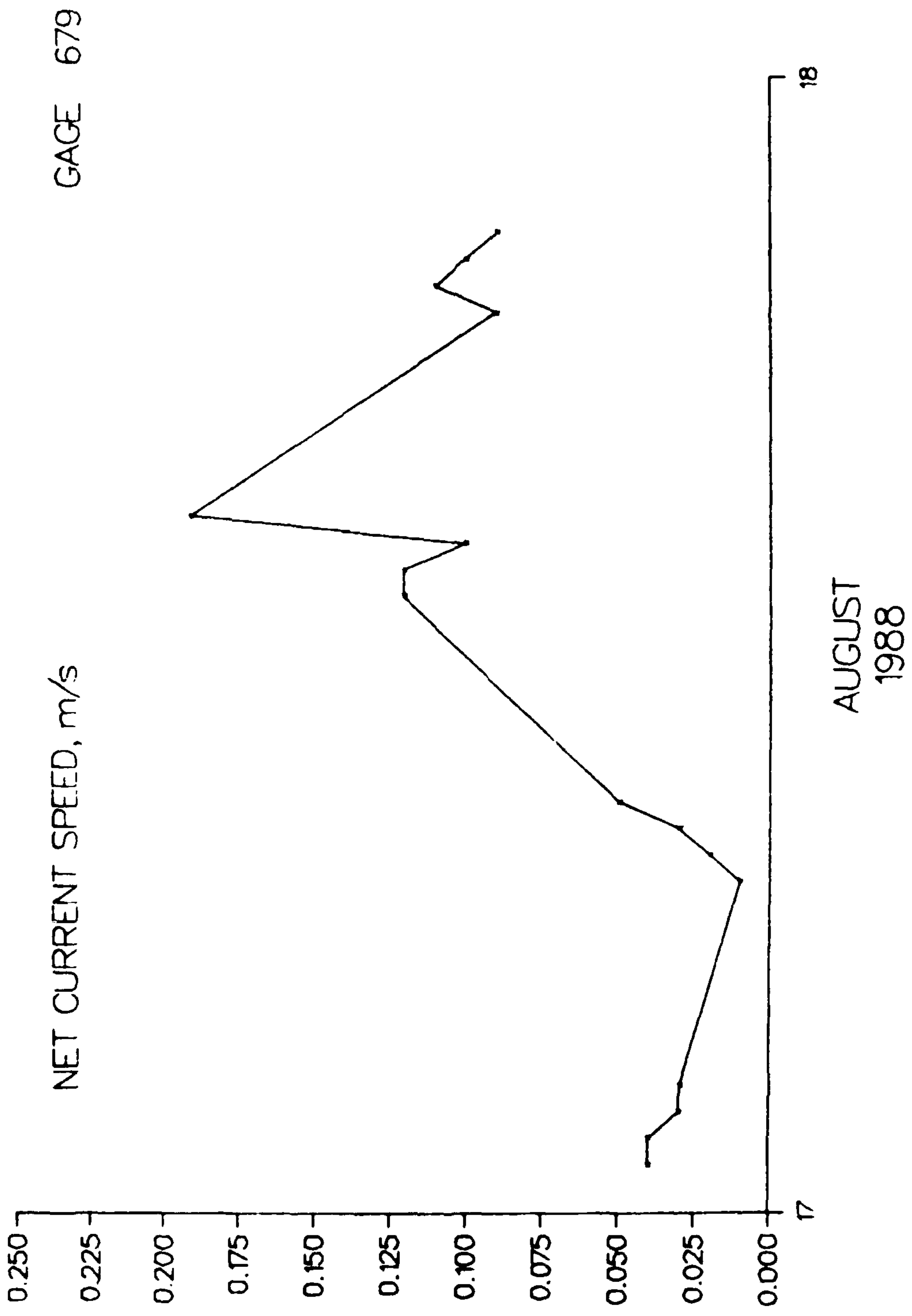


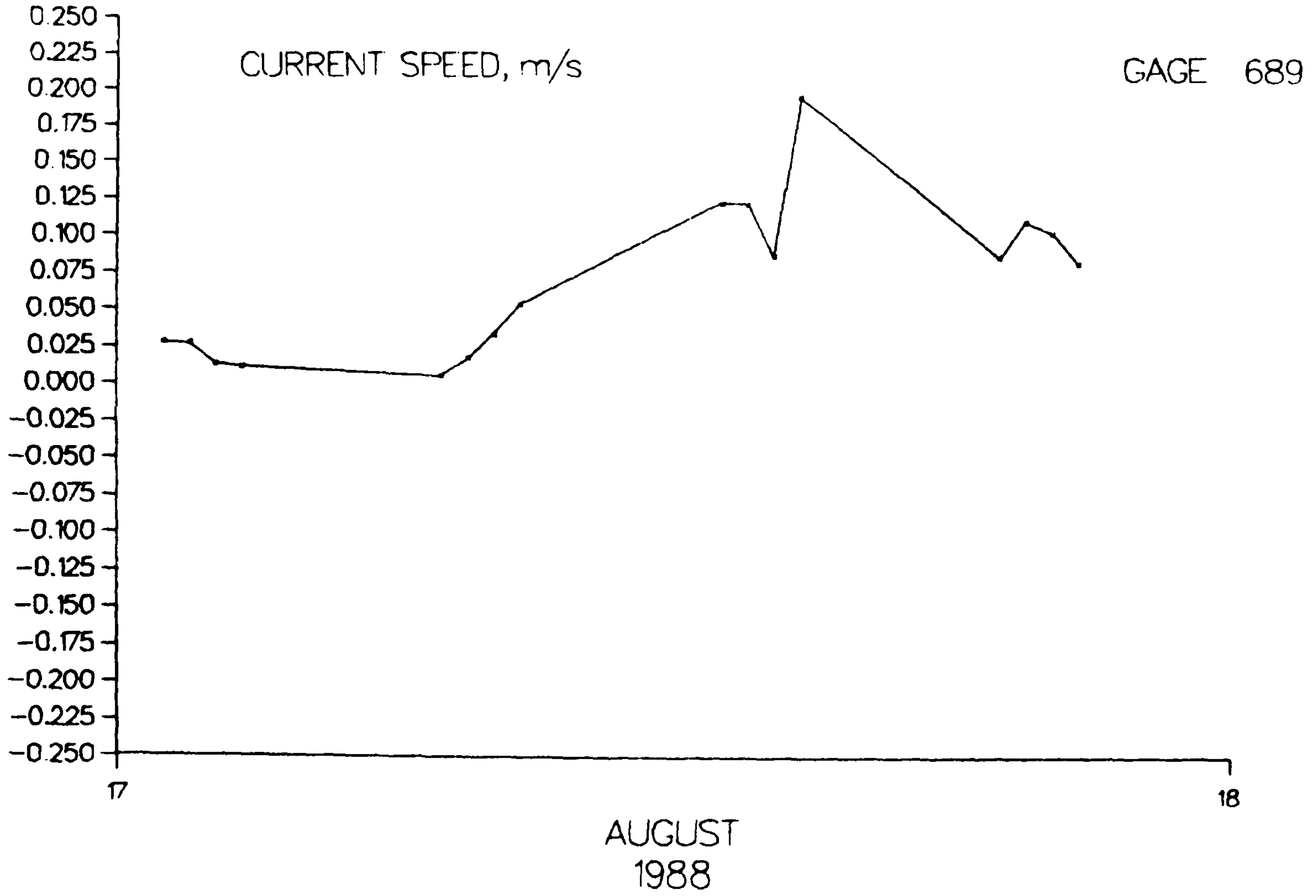
DIRECTIONAL SPECTRUM
PUV at SOUTH TRIPOD
17 AUG 1988 at 0842 EST

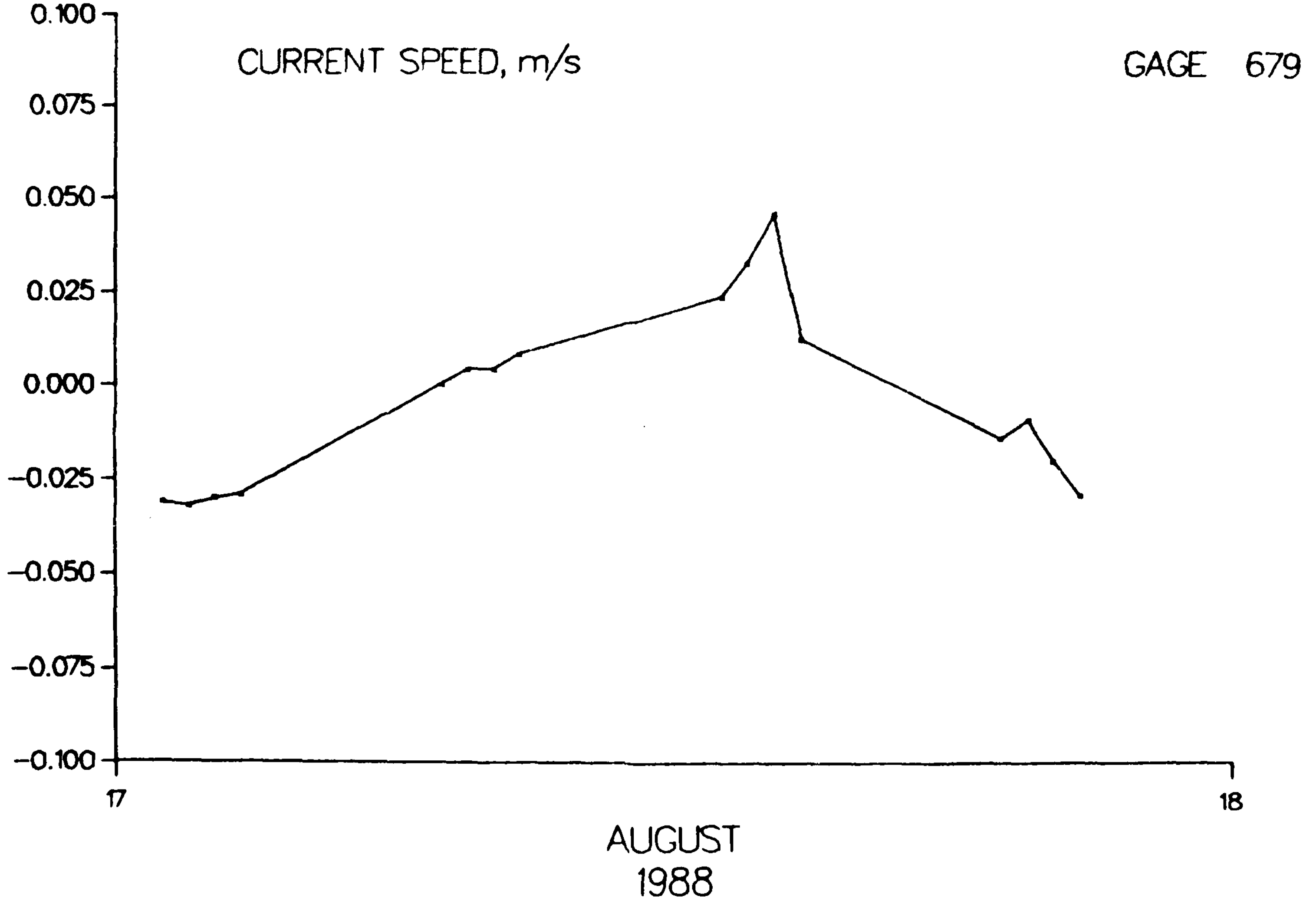


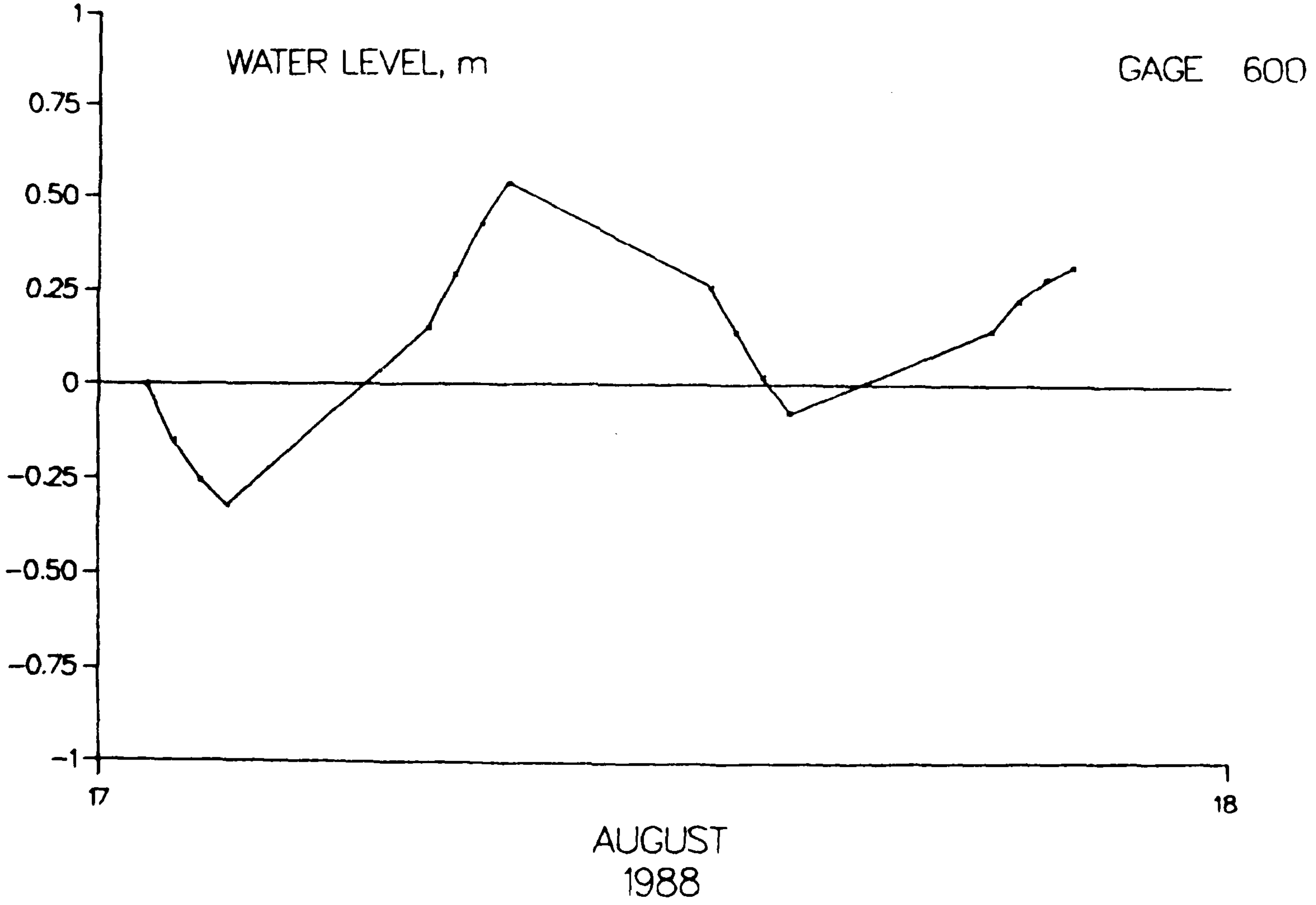

HMO, m
GAGE 621
1
0.8
0.6
0.4
0.2
0
17
18
AUGUST
1988

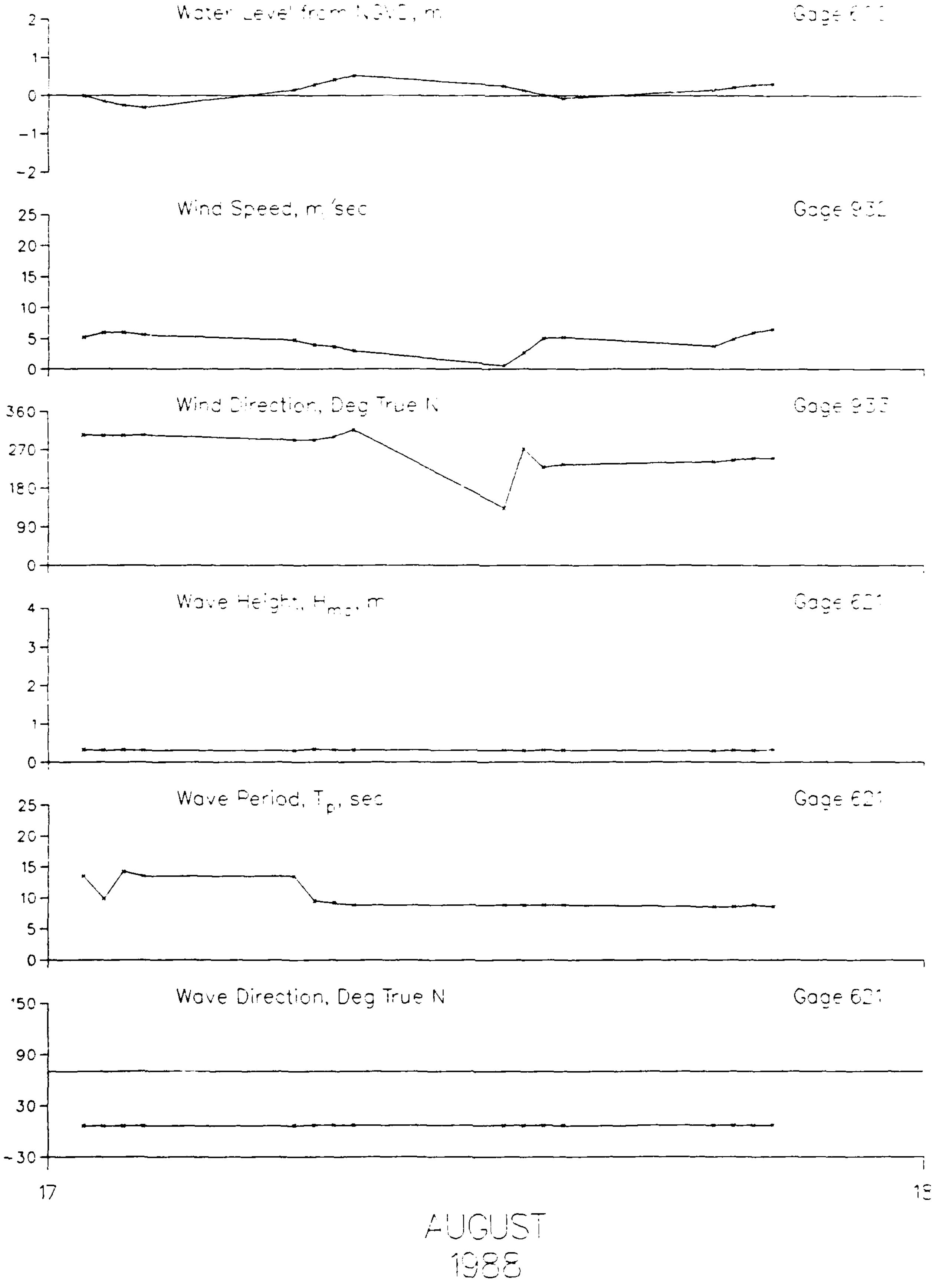

Current Direction, Deg True N
Gage 6T
360
270
180
90
0
17
19
AUGUST
1988


GAGE 679
NET CURRENT SPEED, m/s
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
17
18
AUGUST
1988


CURRENT SPEED, m/s
GAGE 689
0.250
0.225
0.200
0.175
0.150
0.125
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
−0.125
−0.150
−0.175
−0.200
−0.225
−0.250
17
18
AUGUST
1988


CURRENT SPEED, m/s
GAGE 679
0.100
0.075
0.050
0.025
0.000
−0.025
−0.050
−0.075
−0.100
17
18
AUGUST
1988


WATER LEVEL, m
GAGE 600
1
0.75
0.50
0.25
0
-0.25
-0.50
-0.75
-1
17
18
AUGUST
1988


Water Level from NGVD, m
Gage 611
2
1
0
-1
-2
Wind Speed, m/sec
Gage 932
25
20
15
10
5
0
Wind Direction, Deg True N
Gage 932
360
270
180
90
0
Wave Height, H_{mo}, m
Gage 621
4
3
2
1
0
Wave Period, T_p, sec
Gage 621
25
20
15
10
5
0
Wave Direction, Deg True N
Gage 621
150
90
30
-30
17
18
AUGUST
1988

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7. AUTHOR(s) R. M. Brooks W. D. Corson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS US Army Engineer Waterways Experiment Station Coastal Engineering Research Center PO Box 631, Vicksburg, Mississippi 39180-0631		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS DEPARTMENT OF THE ARMY US Army Corps of Engineers Washington, DC 20314-1000		12. REPORT DATE August 1984 13. NUMBER OF PAGES 54
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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Ocean waves--Atlantic coast--Statistics (LC)
Atlantic coast (United States)--Statistics (LC)
Pressure (LC) WIS (Wave Information Study) (WES)
Winds (LC)
Water levels (WES)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report is a summary of seven data sets produced and archived by the the Wave Information Study (WIS) for the Atlantic coast: (1) surface pressure fields, (2) Phase I hindcast wind fields, (3) Phase I deepwater wave data, (4) Phase II hindcast wind fields, (5) Phase II hindcast wave data, (6) Phase III nearshore wave data, and (7) water level data. The wave parameters from the data sets listed in 2, 5, and 6 have been incorporated into WIS's computer-based data system, the Sea-State Engineering Analysis System (SEAS), which is

(Continued)

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APPENDIX E

COASTAL ZONE COLOR SCANNER

The CZCS and seven other discrete sensors were incorporated into the Nimbus-7 satellite launched from Cape Canaveral by a Delta 2910 on 23 October 1978. The CZCS possessed an orbit inclined at about 99 degrees and having a period of 104 minutes. The repeat cycle was around six days. The CZCS was a spatially imaging multispectral scanner with IFOV of 865 microrads, which translates into a pixel size of 825 X 825 meters.

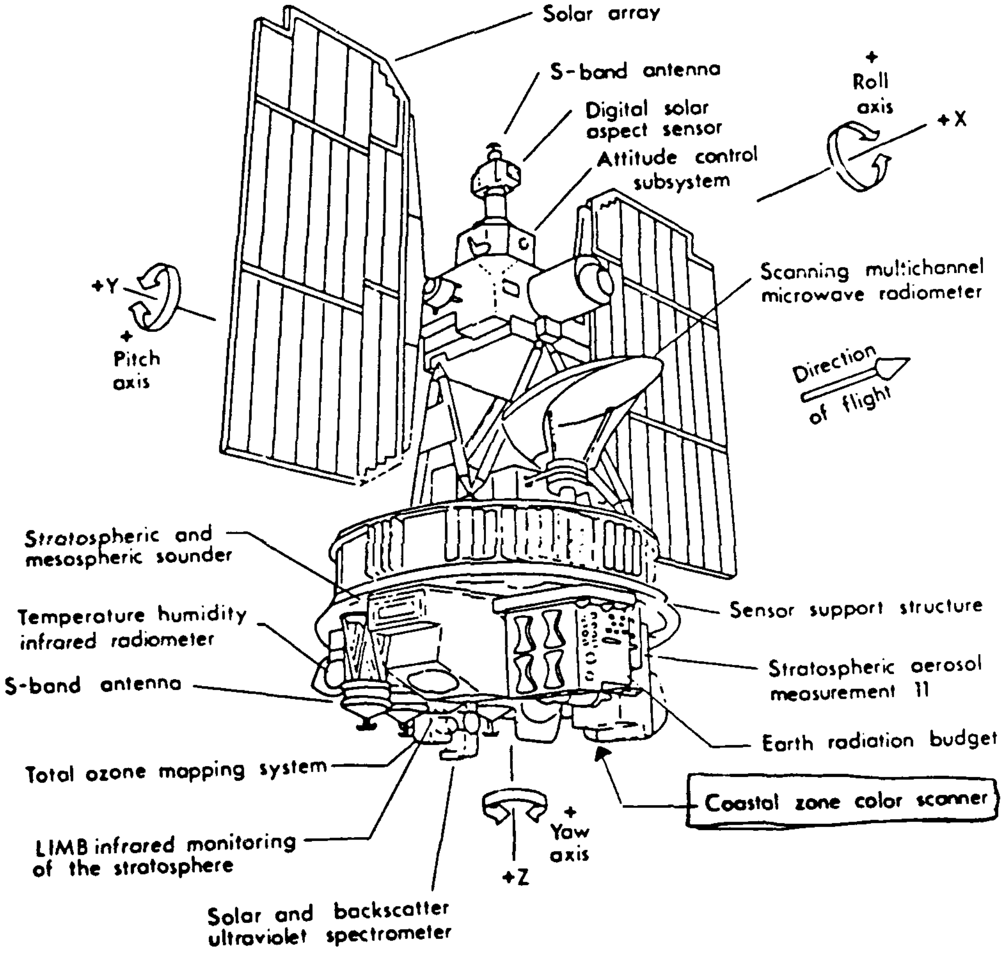
The Table below provides the optical characteristics of the CZCS [6].

BAND	BANDWIDTH (nm)	UTILITY
1	433-435	low chlorophyll
2	510-530	high chlorophyll
3	540-560	suspended solids
4	660-680	atmospheric correc

5	700-800	land-sea boundary
6	10500-12500	sea-surface temp.

The spectroradiometer used in this experiment possesses bands that allow an emulation of the CZCS system The following table shows the channel wavelengths

CHANNEL	WAVELENGTH (nm)
1	439.6
2	490.2
3	513.9
4	551.2
5	669 (+/- 10)



The *Nimbus-7* satellite (after NASA 1976)

APPENDIX D

APPENDIX C

BULK PROPERTIES MODEL TO ALLOW BOTTOM REFLECTIVITY TO BE FOUND

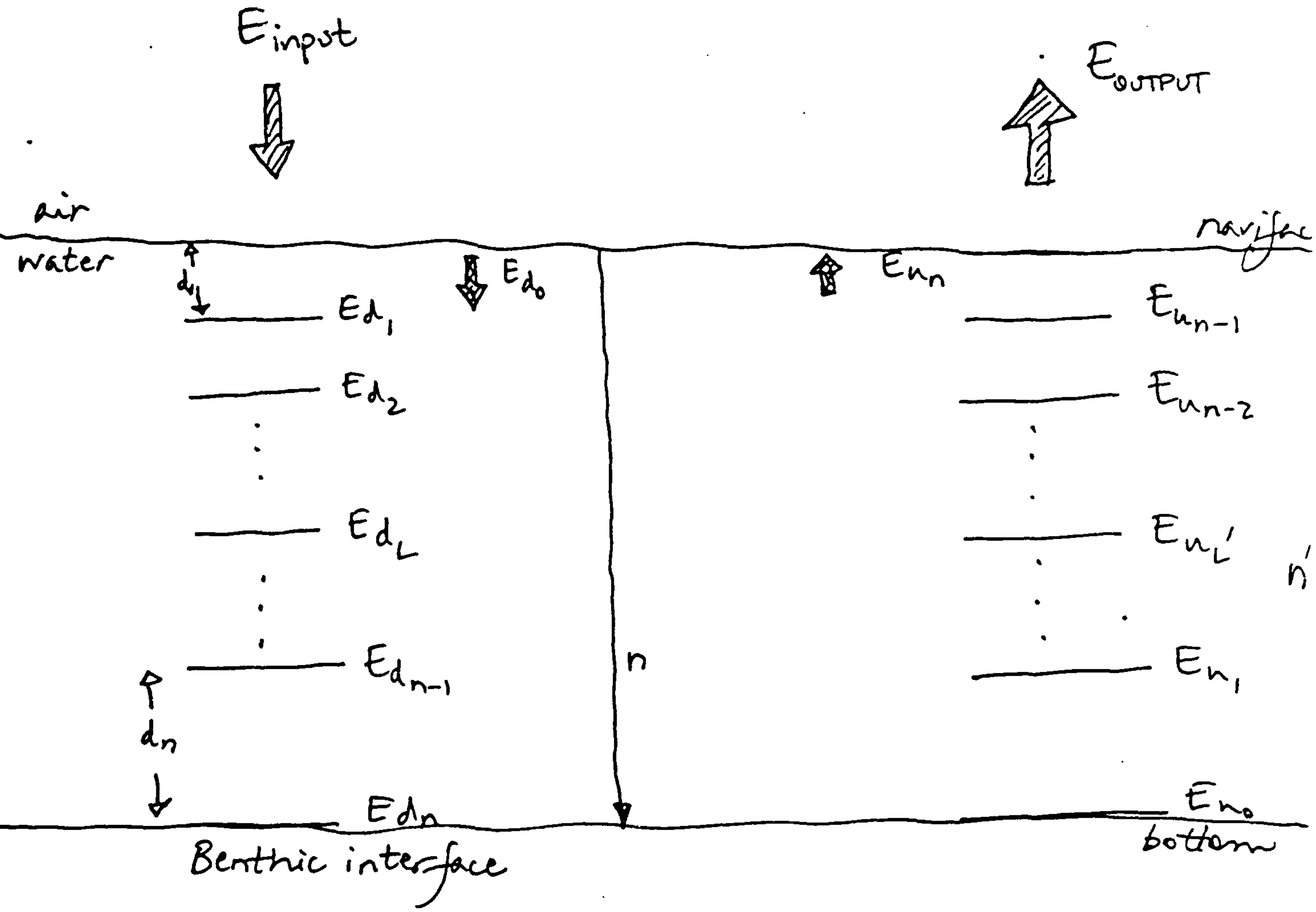


FIG 1.

Assumptions

1. The sea is passive.
2. k is not necessarily constant. It can change at each level.
3. Levels can be of different thicknesses.

Understandings

1. $E_{do} := E_{input} \cdot t_s \; \square$; where T-sub s is the transmissivity of the interface.

2. $E_{output} := E_{un} \cdot t_s$

3. $D := \sum_i d_i$ and $D := \sum_i u_i$

   where i=1 ..n

4. $n := |n'|$ where n' is the number associated with the layers from bottom up.

5. $E_{uo} := E_{dn} \cdot R_b$ where r sub-b is the bottom reflectivity.

6. $N := n + 1$ where n is the number of layers, or intervals

7. $E_{do'} := E_{un} \cdot R_w$ where E sub-do' is the upwelling reflected from the naviface.

8. $E_{do}^{<\alpha>} := E_{do} + E_{do'}$

9. $R_1 := \dfrac{E_{ul'}}{E_{dl}}$

Calculations

1. $E_{ul'} := E_{uo} \cdot \exp\left[-\left[\sum_{i} k_{ui} \cdot u_{i}\right]\right]$ where i=1 ..l'

2. $E_{dl} := E_{do}^{\langle\alpha\rangle} \cdot \exp\left[-\left[\sum_{i} k_{di} \cdot d_{i}\right]\right]$ where i=1 ..l

3. $R_{l} := \left[\frac{E_{uo}}{E_{do}^{\langle\alpha\rangle}}\right] \cdot \frac{\exp\left[-\left[\sum_{i} k_{ui} \cdot u_{i}\right]\right]}{\exp\left[-\left[\sum_{i} k_{di} \cdot d_{i}\right]\right]}$ where i in the numerator sums from 1 to l' and in the denominator from 1 to l.

4. Since, $E_{uo} := E_{dn} \cdot R_{b}$ and $E_{dn} := E_{do}^{\langle\alpha\rangle} \cdot \exp\left[-\left[\sum_{i} k_{di} \cdot d_{i}\right]\right].$

then

$$R_{l} := \left[\frac{R_{b}}{E_{do}^{\langle\alpha\rangle}}\right] \cdot E_{do}^{\langle\alpha\rangle} \cdot \exp\left[-\left[\sum_{i} k_{di} \cdot d_{i}\right]\right] \cdot \frac{\exp\left[-\left[\sum_{i} k_{ui} \cdot u_{i}\right]\right]}{\exp\left[-\left[\sum_{i} k_{di} \cdot d_{i}\right]\right]}$$

where i in the first exponential goes from 1 to n, or the total number of layers present. In the numerator, i goes from 1 to 1'; and in the denominator 1 goes from 1 to 1.

5. $$R_{l} := R_{b}\cdot\exp\left[-\left[\sum_{i} k_{di}\cdot d_{i}\right]\right]\cdot\exp\left[-\left[\sum_{i} k_{ui}\cdot u_{i}\right]\right]$$

where i in the first eponential goes from 1+1 to n and in the second goes from 1 to 1'.

6. Note that the first and second exponential expressions cover the same region. Whereupon,

$$R_{l} := R_{b}\cdot\exp\left[-2\cdot\left[\sum k_{ui}\cdot u_{i}\right]\right]$$

where we assume the upwelling and downwelling k's are equal.

7. In terms of E sub-u and E sub-d;

$$\frac{E_{ul'}}{E_{dl}} := R_{b}\cdot\exp\left[-2\cdot\left[\sum_{i} k_{ui}\cdot u_{i}\right]\right]$$

8. The best reckoning of R sub-b will be when we are one interval above the bottom; then, 1'=1 and

$$R_b := \left[\frac{E_{u1}}{E_{d(n-1)}}\right] \cdot \exp\left[k_{u1} \cdot u_1\right] \cdot \exp\left[k_{d(n-1)} \cdot u_1\right]$$

where, in the above, the upwelling and downwelling have been treated separately.

APPENDIX D

APPENDIX D

LASER POWER AND SNR CALCULATIONS

POWER RECEIVED

The following is a quick, heuristic derivation of a laser received power equation and a SNR equation for the system Bulk properties of the water mass are used.

If the power produced by the laser is P, then after exiting the aircraft, the power has become diminished by passage through the transmitting optics, which gives

$$P T_t$$

and when coupled with losses in the atmosphere, we have at the surface of the water

$$P T_t T_A$$

Losses in the air-water interface are allowed for by a factor

$$T_s$$

or, altogether,

$$PT_tT_AT_s$$

The laser beam produces a spot on the water surface and on the ocean floor The spot size on the ocean floor will be a function of the beam divergence, turbidity in the water and the water depth Given the beam divergence and the water depth, one can estimate the bottom spot size using results provided by Duntley [5]. Duntley provides a factor to be included in the calculation that taken account of the spot size and how it affects the irradiance at depth. Using this factor, W, the reflectivity from the bottom, and the attenuation to the bottom (in exponential form), we can write

$$P_tT_tT_AT_s\rho W\exp[-KD/\cos\phi]$$

The reflected laser light traverses the water on its return path and exits the surface. It travels through the atmosphere Including the attenuation factor and transmission factors, we have

$$P_t T_t T_A^2 T_s^2 \rho W \exp[-2KD/\cos\phi]$$

If we assume the bottom is a Lambertian reflector, rho, then in the upper hemisphere, the upwelling radiation will spread and decrease as

$$\frac{\cos\phi}{\pi * (\text{distance to receiver})}$$

The receiver will intercept the beam and degrade its power through its receiving optics. Taken altogether, then, we have

$$\frac{P_t T_t T_A^2 T_s^2 T_R \rho W A \exp\left[-2KD/\cos\phi\right] \cdot \cos\phi}{\pi * (\text{DISTANCE})}$$

The angle phi which represents the angle in the water can be transformed into the incidence angle, theta, in air via Snell's Law. If this is done, the resultant expression is.

$$r = \frac{P_t T_t T_A^2 T_s^2 T_R \rho W A \left(1-\frac{9}{16}\sin^2\theta\right)^{1/2} e^{-2KD/\sqrt{1-\frac{9}{16}\sin^2\theta}}}{\pi \left(\frac{h}{\cos\theta} + \frac{D}{\sqrt{1-\frac{9}{16}\sin^2\theta}}\right)^2} \qquad [1]$$

Equation [1] provides a calculation for the power received by the receiver.

SNR CALCULATION

The primary noise source is the sun. The solar irradiance can be written

$$E_s * \Delta\lambda$$

where E_s is the solar spectral irradiance. The reflectance of the sun off the water can be given by

$$E_s * \Delta\lambda * (1 - T_s)$$

As before, the light is attenuated in its passage through the atmosphere by both aerosols and geometry. If we wish to state the power seen at the receiver due to the solar irradiance, then we can multiply the spectral solar irradiance by the area being viewed. This involves the field of view of the receiver, the distance from the receiver to the area encompassed by the field of view, and a

$$\frac{1}{\cos\theta}$$

term as an areal weighting factor. Altogther, including an aperture term for the receiver, we can write

$$P_{SS} = \frac{E_S \, \Delta\lambda \, (1 - T_S) \, T_A \, T_R \, A \, \alpha_R^2}{\pi}$$

[2].

However, solar light will also pass through the water surface. Thus, another term needs to be included. Essentially, this follows earlier arguements with apposite transmission factors, exponential attenuation factors, and attenuation due to geometric spreading in the upper hemisphere. Altogether, the term can be written as

$$P_{SB} = \frac{E_S \, \Delta\lambda \, T_S^2 \, T_A \, T_R \, \rho \, A \, \alpha_R^2 \exp\left[-2KD\right]}{\pi}$$

[3]

The total solar noise becomes the sum of [2] and [3].

Another source of noise is that due to the photomultiplier (PMT). The noise equivalent power (NEP) for a typical PMT can be written

$$N = \frac{1}{S}\sqrt{2qIG\Delta f} \qquad [4]$$

In the above, N is the NEP in watts, q is the charge on the electron, I is the anode dark current in amperes, G is the amplification ratio for the current, f is the electronic bandwidth in Hz, and S is the anode radiant sensitivity in amps/watt at a given channel.

The calculation of the signal to noise ratio (SNR) is best performed in photons. One may transform watts into photons/sec by using the relation

$$\frac{\lambda}{hc}$$

Then, knowing the time interval, t, during which our measurement is made, and, if we know the quantum efficiency of the device, then we can translate power into photons. For example, the number of photons available from the laser pulse will be

$$S_r = P_r * \left(\frac{\lambda}{hc}\right) * \Delta t * \eta \quad [5].$$

The noise present, as previously considered, consists of three parts. In terms of photons, these may be written as in the following:

$$\sqrt{S} \quad , \quad \sqrt{S} \quad , \quad N\left(\frac{\lambda}{hc}\right)\Delta t \eta$$

These components can be ratioed appropriately (assuming Poisson statistics) to give

$$SNR = \frac{S_r}{\left[S_r + S_N + N^2\left(\frac{\lambda}{hc}\right)^2 \Delta t^2 \eta^2 \right]^{1/2}}$$

[6].

For the case of the data provided by station 3 for the first Duck data set, the following table gives the power received and the signal to noise ratio for the assumed system parameters. In this, the noise assumed for the PMT is 1.95E-15 watts and the quantum efficiency is 15 %. Obviously, other calculations can be made if one wishes to speculate on different system or water column parameters.

SYSTEM PARAMETERS

POWEROUT=.75 mJ/PULSE
APERTURE=6 INCHES
MEASURE TIME=2.5E-09
RECEIVER FOV=.008 RADS
TRANSMISSION OPTICS= .5
RECEIVER OPTICS= .5
ATMOSPH.TRANSMISSION= .98
FILTER BANDWIDTH= .01 micrometers
SCAN ANGLE=15 DEGREES
SPECTRAL SOLAR IRRAD.=8.00E-02
ALTITUDE=500m

WATER COLUMN PARAMETERS
(STATION 3 DATA)

DIFFUSE ATTENUATION COEFF.=.577
BEAM SPREAD FACTOR= .16
INTERFACE TRANSMISSION=.6
BOTTOM REFLECTIVITY= .12

The diffuse attenuation coefficient used will be an average value over the water column for the channel closest to the doubled Nd:YAG green line (532 nm). Similarly, the bottom reflection and interface transmission will be taken from the data of the channel that most closely approximates the 532 nm line.

POWER RETURNED TO RECEIVER	SIGNAL TO NOISE
7.595E-09 Watts	.2564

Obviously, we would not be able to see the return signal. This is in line with the 'KD ' limits of the system. The KD value for this set of parameters is 3.17. Since the limits of the system are KD=3.00, the system should not be expected to give a readable signal back.

Interestingly enough, if in the above table of water column values we change only the bottom reflection coefficient to a higher value, say .3, the SNR becomes .636 which is approaching the unity break-even-point for the same KD value as the first case.

As a last situation, suppose all else is the same as in the tabulated list but for the k value, which becomes .4. The KD value of the system is now 2.2 and the SNR is 3.6 -- a measureable returning irradiance.

Fig. 57 gives a plot of k vs d for a kd=3.0.

APPENDIX E

APPENDIX E

CZCS ALGORITM CALCULATIONS

Austin and Petzold (4) developed an algorithm for the calculation of the diffuse attenuation coefficient for two of the CZCS wavelengths (490 and 520 nm) by rationing certain bands of CZCS and comparing these to field data and obtaining a regression relationship between the data and the ratio.

The relevant algorithm for the 490 nm k-value can be written as

$$K(490) = 0.0883\left(\frac{L_n(443)}{L_n(550)}\right)^{-1.491} + K_w(490) \quad [1].$$

The germane algorithm for the 520 nm band is

$$K(520) = 0.0663 \left(\frac{L_w(443)}{L_w(550)} \right)^{-1.398} + K_w(520) \quad [2]$$

The graph in Fig 58 gives the calculated values of k for both 490 nm and 520 nm to compare with the measured k for the stated stations and relevant wavelengths.

The abscissa in the plot numbers the stations sequentially starting with the first Duck data set and terminating with the last Duck data set.

As is seen in the plots, the algorithm in some cases does a good job of giving a reasonable value of the downwelling k for certain stations. For example, for the 490 nm k-value, stations 1, 2, 4, and 6 are fairly well represented. The 520 nm k-value is closely calculated in stations 1, 2, 4, and 6. These are the same stations as for the 490 nm result. The points at stations 3 and 5 show far more erratic behaviour. Station 3 here is the station 3 of Duck data set one, and station 5 is the second station done for the second time in the last Duck data set. Observing the irradiance ratio of station 3, in Fig 12, it appears to behave in an unusual manner showing a large 'dip' in these ratios as a function of depth.

Nothwithstanding, the Austin and Petzold algorithm, upon a cursory examination of the calculated and measured k's, provides a seemingly acceptable way to find the k of a water mass from orbit or from an airborne platform. However, there appears to be still some water mass features that may inhibit the algorithm from correctly computing the k-value. To study and understand the causes for its failure under certain conditions holding in the water column is important.

APPENDIX F

SHIP/SCIENCE LOG

STA 1 (660')

Date 6/18/88
Lat
Long
Investigator Estep
Time 1236 EST

Surface Conditions

Wave Height 12"
Direction from SE
% Whitecaps 0%

Current(s)

Direction from SE
Speed 1/3 m/sec (? guess)

Bottom Conditions

Depth 7.5' (2.28 m)
Geology
Grab Sample #
Biology

see sample

Weather Conditions

Cloud Cover/Type Cirrus; 5%
Wind Speed
Direction SE

Water Conditions

Secchi Depth 3.5'
Color/Changes green

Aerial Overflight

Time Proposed
1300 to 1330

Remarks:

1. swell coming in from southeast. 2½'.
2. Haze evident

(660')

DATA LOG

Radiometer Measurements

STA 1.

Investigator Estep

Date 6/18/88

Time 1240

Depth above surface

Temperature 21°C

High Voltage Setting 34(up) 44(down)

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	431624	86124	-06	-05
2	695016	128480	"	"
3	795504	133044	"	"
4	912600	150652	"	"
5	438056	116196	"	"

Depth just below surface

Temperature 15°

HV Set 44 & 34 (as

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	3280	50460	-06	-05
2	40896	90482	"	"
3	54160	94520	"	"
4	69720	104120	"	"
5	11812	58344	"	"

Φ) = 7.24 * E13

G(λ) = 1 * E14

STA 1.

DATA LOG

Radiometer Measurements

Investigator Estep

Date 6/18/88

Time 1250

Depth 1m

Temperature 14°

High Voltage Setting 34 + 44 (as before)

	Mirror down		Mirror up		
Filter Position	Counts		Counts	Pitch	Roll
1	8056		24012	-05	-06
2	25417		56056	"	"
3	34576		62136	"	"
4	46018		69056	"	"
5	7936		34193	"	"

Depth 2

Temperature 15

HV Set 44

	Mirror down		Mirror up		
Filter Position	Counts		Counts	Pitch	Roll
1	2048		61966	-06	-05
2	8548		164276	"	"
3	12536		198532	"	"
4	20640		265192	"	"
5	3472		70643	"	"

[illegible]

STA 2 (1220')

SHIP/SCIENCE LOG

Date 6/18/88 Lat ______ Long ______

Investigator Estep Time 1405

Surface Conditions

Wave Height 12"

Direction from SE

% Whitecaps 0

Current(s)

Direction ½ m/sec / SE

Speed ______ / ______

Bottom Conditions

Depth 4.2 m

Geology ______

Grab Sample # ______

Biology ______

Weather Conditions

Cloud Cover/Type 2% cirrus

Wind Speed ______

Direction E

Water Conditions

Secchi Depth 4.4'

Color/Changes green

Aerial Overflight

Time Proposed 1300- 1330

Remarks:

1. Lots of Haze

47.7
28.7
19.0

DATA LOG

STA 2 (1220')

Radiometer Measurements

Investigator Estep

Date 6/18/88

Time 1215

Depth just above Surface **Temperature** 25

High Voltage Setting 34 & 44 (as before)

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	43000	89200	-06	-05
2	76000	138150	"	"
3	87000	145200	"	"
4	89000	160750	"	"
5	26000	126400	"	"

Depth Just Below Surface **Temperature** 17 HV Set

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	② 49000	22500	-6	-7
2	② 40500	44000	"	"
3	② 31500	50000	"	"
4	① 119000 (53052)	75000	"	"
5	① 53500 (23800)	33500	"	"

① HV = 5B

② HV = 44

DATA LOG

Radiometer Measurements

STA 2(12

Investigator Carpenter

Date 18 June 88

Time 1446 EDT

Depth 1m **Temperature** 15

High Voltage Setting 44/5B

44 up looking
5B down looking

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	77000	59500	-6	-6
2	195000	140000	"	"
3	248000	175000	"	"
4	305000	195000	"	"
5	26500	48000	"	"

Depth 3m **Temperature** 15 HV Set 44/5B

up Down

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	12500	23500	-6	-5
2	55500	75000	"	"
3	75000	92000	"	"
4	114000	69000	"	"
5	8000	10500	"	"

STA 2 (1220)

DATA LOG

Radiometer Measurements

Investigator Estep

Date 6/18/85

Time

Depth 4m

Temperature 16 °C

High Voltage Setting 44(up)/58 down

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	5644	12544	-06	-05
2	30783	54913	"	"
3	58756	71555	"	"
4	81522	92552	"	"
5	6012	13152	"	"

Depth 5m

Temperature 14°C

HV Set

too close too bttm.

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1			-06	-05
2			"	"
3			"	"
4			"	"
5			"	"

STA. 5. (1900)

SHIP/SCIENCE LOG

Date 6/18/88 Lat ______ Long ______

Investigator Estep Time 1540 EST

Surface Conditions

Wave Height 4"

Direction SE

% Whitecaps 0

Current(s)

Direction SE

Speed little

Bottom Conditions

Depth 7.5m

Geology ______

Grab Sample # ______

Biology ______

Weather Conditions

Cloud Cover/Type Cumulo-cirrus/

Wind Speed —

Direction SE

Water Conditions

Secchi Depth 7.2'

Color/Changes green

Aerial Overflight

Time 1535

Remarks:

1) still hazy

2)

DATA LOG

Radiometer Measurements

Investigator Estep

Date 6/18/88

Time 1552 (STA 3)

Depth just abv surface   Temperature 19°C

High Voltage Setting 34 up/44 down

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	25952	35852	.05	-06
2	42942	48869	"	"
3	46566	48742	"	"
4	50444	50562	"	"
5	19453	32332	"	"

Depth just below surface   Temperature 17°C   HV Set 34/44 (as [illegible]

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	304	16158	-05	-06
2	17320	27304	"	"
3	19232	29775	"	"
4	21564	30704	"	"
5	2436	12780	"	"

1. clouds moving in now.

DATA LOG

Radiometer Measurements

STA 3 (1900

Investigator Estep

Date 6/18/88

Time 1024

Depth 1m

Temperature 17 °C

High Voltage Setting 34/44

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	352	9684	-05	-06
2	11623.	16482	"	"
3	15483	19992	"	"
4	17153	20583	"	"
5	1664	6563	"	"

Depth 2m

Temperature 17°C

HV Set 34/44

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	928	38840	-05	-06
2	7624	97184	"	"
3	10512	107894	"	"
4	13255	120533	'	"
5	984	25872	"	"

1. Clouds coming in.

DATA LOG

Radiometer Measurements

STA(3) 113

Investigator Estep

Date 6/18/88

Time 1633

Depth 3m

Temperature 17°C

High Voltage Setting 44

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	1872	29553	-06	-05
2	7082	77443	"	"
3	9232	89562	"	"
4	12986	104542	"	"
5	768	15362	"	"

Depth 4

Temperature 17°C

HV Set 44

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	736	17358	-06	-05
2	5386	55683	"	"
3	6954	80921	"	"
4	10456	93524	"	"
5	614	7336	"	"

STA 3 (1[illegible]

DATA LOG

Radiometer Measurements

Investigator Estep

Date 6/18/88

Time 1646

Depth 5

Temperature 17°C

High Voltage Setting 44

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	496	6892	-06	-05
2	2046	29852	"	"
3	3216	36555	"	"
4	4403	45694	"	"
5	368	2512	"	"

Depth 6

Temperature 17°C

HV Set 5B

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	576	15884	-06	-05
2	4436	71756	"	"
3	7616	106968	"	"
4	12430	124550	"	"
5	656	5760	"	"

STA 2.1 (D2)

Station 1220 Strong tidal current throughout this Station from North → South

DATA LOG

Radiometer Measurements

Investigator Hsu

Date 8-17-88

Time 1415

Depth

Temperature 32

High Voltage Setting $\overset{90}{46}/\overset{38}{26}$

above surface

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	250,000	28,000	-02	-08
2	450,000	49000		
3		56,000		
4		56,000		
5		38,000		

Depth .000V/0

Temperature 24

HV Set $\overset{90}{46}$/

just below surface

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	~~446,000~~ 74,000		-03	-11
2	201,000			
3	238,000			
4	285,000			
5	25,000			

Station
1220

DATA LOG

Radiometer Measurements

Investigator ____________

Date 8-17-88

Time 1429

m . Depth 1000 1009V

Temperature 20

High Voltage Setting 46/36 70 54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	66,000	3400,000	-03	-13
2	198,000	750,000		
3	241,000	850,000		
4	295,000	750,000		
5	23,000	350,000		

2m Depth 1020V/001

Temperature 20

HV Set 46/36 70 54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	66,000	325,000	-02	-13
2	185,000	600,000		
3	234,000	650,000		
4	304,000	625,000		
5	22,000	235,000		

Station
1220
Secchi =
14'

DATA LOG

Radiometer Measurements

Investigator ____________

Date 8-17-88

Time 1438

Depth .030 ✓/002 Temperature 20

3 pm

High Voltage Setting $\overset{70}{46}$/$\overset{54}{36}$

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	50,000	200,000	-04	-12
2	160,000	430,000		
3	214,000	485,000		
4	283,000	575,000		
5	20,000	140,000		

7
3m

Depth .039 ✓/003 Temperature 20 HV Set $\overset{70}{46}$/$\overset{54}{36}$

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	32,000	133,000	-04	-12
2	124,000	315,000		
3	174,000	360,000		
4	250,000	405,000		
5	15,000	72,000		

Station
1220

DATA LOG

Radiometer Measurements

Investigator ____________ Date 8-17-88

Time 1445

5 Am

Depth 1046V/004 Temperature 20

High Voltage Setting $\overset{70}{46}$/$\overset{54}{36}$

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	18,000	68,000	-02	-09
2	86,000	200,000		
3	128,000	215,000		
4	197,000	290,000		
5	11,000	230,000		

6 m

Depth 1056V/005 Temperature 20 HV Set $\overset{70}{46}$/$\overset{54}{36}$

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	9900	38,000	-05	-04
2	45,000	130,000		
3	72,000	162,000		
4	113,000	221,000		
5	8,000	20,000		

Station 1220

DATA LOG

Radiometer Measurements

Investigator

Date 8-17-88

Time 1452

Depth 1

Temperature 20

High Voltage Setting 46 70 / 36 54

5+ m

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	9,700	27,000	-09	-04
2	46,000	99,000		
3	66,000	137,000		
4	109,000	175,000		
5	86,000	17,000		

Depth 000 Temperature 25 HV Set 26

resurface readings

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1		13,000	-06	-06
2		46,000		
3		52,000		
4		56,000		
5		42,000		

STA 2.2 (D2)

1220 redo
plane over
again

DATA LOG

Radiometer Measurements

Investigator Hsu

Date 8-17-88

Time 4:07 pm

Depth

Temperature 23

38
High Voltage Setting 126

just above surface water on mechanism

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1		25,000	-.06	-.06
2		37,000		
3		39,000		
4		42,000		
5		33,000		

Depth 000/000 **Temperature** 25 HV Set 56

86

just below surface

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	86,000		.01	-.06
2	75,000			
3	880,000			
4	733,000			
5	258,000			

Station 1226
Redo

DATA LOG

Radiometer Measurements

Investigator ____________

Date 8-17-88

Time 1615

1m

Depth .00$\overset{Y}{9}$/000 Temperature 24

High Voltage Setting $\overset{86}{56}/\overset{64}{36}$

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	237,000	259,000	-08	-17
2	727,000	415,000		
3	894,000	525,000		
4	1,096,000	500,000		
5	72,000	250,000		

2m

Depth .01$\overset{v}{7}$/001 Temperature 24 HV Set $\overset{86}{56}/\overset{54}{36}$

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	178,000	170,000	-03	-10
2	605,000	315,000		
3	785,000	400,000		
4	1,027,00	375,000		
5	59,000	135,000		

DATA LOG

Radiometer Measurements

Station 1220 1020

Investigator ____________

Date 8-17-89

Time 1622

3m. Depth .030/002 Temperature 25

High Voltage Setting 56/36 86/54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	145,000	108,000	-01	-10
2	518,000	258,000		
3	690,000	295,000		
4	895,000	325,000		
5	50,000	75,000		

4m Depth .040/003 Temperature 22 HV Set 56/36 86/54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	82,000	61,000	-07	-06
2	338,000	165,000		
3	498,000	195,000		
4	700,000	235,000		
5	40,000	33,000		

5m Depth .050/004 Temp 22 HV Set 56/36 86/54

Filter Pos	Mirror down Counts	Mirror Up counts	Pitch	Roll
1	32,000	23,000	.06	.05
2	157,000	74,000		
3	253,000	100,000		
4	368,000	119,000		
5	22,000	11,000		

see back for last Readin

Plane first Pass 1640
2nd " 1650
3rd " 1654.

Station 220

DATA LOG

Radiometer Measurements

Investigator ________________ Date 8/17/88

Time 1640

5m+ Depth .053V/005 Temperature 21

High Voltage Setting 56/36 ([illegible])

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	16000	15000	-08	-05
2	22000	65,000		
3	115,000	5[illegible],000		
4	188000	73,000		
5	12,000	7,000		

time 1648
1112

resurface

Depth ________ Temperature ________ HV Set 56

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	169000			
2	490,000			
3	563,000			
4	700,000			
5	56,000			

above Surface

Time 1650

Mirror up

HV Set 36

Temp 27

	Mirror up
1	320,000
2	540,000
3	580,000
4	640,000
5	675,000

STA 3. (D2)

Station 1900

DATA LOG

Radiometer Measurements

Investigator ASW

Date 8-17-88

Time 11:23

(above the surface)

Depth

Temperature

High Voltage Setting 68 44 / 34 52 (1 sec Avg)

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	175,000	487,000		
2	285,000	770,000		
3	295,000	808,000		
4	325,000	884,000		
5	165,000	644,000		

(just below the surface) voltage

Depth 0

Temperature

HV Set 68 44

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	54,000			
2	121,000			
3	138,000			
4	164,000			
5	24,000			

below 

Station 1900

DATA LOG

Radiometer Measurements

Investigator ____________ Date ____________

Time ____________

1m Depth 0.013 ✓ / 001 Temperature 18

High Voltage Setting 68 52 / 44/34

~~Depth = [illegible]~~

Voltage = .013

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	235,000	235,000		
2	93,000	440,000		
3	113,000	460,000		
4	134,000	530,000		
5	12,000	275,000		

2m Depth .020 ✓ / 001-002 Temperature 19 HV Set 58/34

56 64 52

Voltage: .020

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	200,000	185,000		
2	570,000	385,000		
3	722,000	415,000		
4	~~1,400,000~~ 900,000	523,000		
5	~~75,000~~ 50,000	175,000		

2

- Station
1900

DATA LOG

Radiometer Measurements

Investigator ____________ Date 8-17-88

Time 12:04

3m Depth .030/002-003 Temperature 18-19

High Voltage Setting [illegible] 56/36
86 54

Secchi = 18.5'

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	157,000	208,000	-04	-09
2	515,000	453,000		
3	655,000	515,000		
4	825,000	590,000		
5	[illegible] 37,000	150,000		

4m Depth .040/003 Temperature 19 HV Set 56/36
86 54

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	136,000	183,000	-04	-09
2	493,000	420,000		
3	623,000	455,000		
4	785,000	535,000		
5	27,000	[illegible] 87,000		

3

Station
1900

DATA LOG

Radiometer Measurements

Investigator__________ Date 8-17-88

Time 12:10

5m

Depth .051✓/005 Temperature 18

High Voltage Setting 56/36
84 54

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	108,000	144,000	-05	-08
2	440,000	365,000		
3	570,000	5350?		
4	740,000	27,500		
5	22,000	57,000		

6m

Depth .059✓/005 Temperature 18 HV Set 56/36
84 54

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	82,000	104,000	-04	-08
2	372,000	300,000		
3	521,000	335,000		
4	695,000	398,000		
5	18,000	33,000		

4

Station 1900

DATA LOG

Radiometer Measurements

Investigator ____________ Date 8-17-88

Time 12:20

Depth .069v/006 Temperature 19

7m High Voltage Setting 56/36
86/54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	60,000	67,000	-04	-08
2	316,000	225,000		
3	447,000	270,000		
4	616,000	9,900 ?		
5	14,000	34,000		

8m Depth .079v/008 Temperature 19 HV Set 56/36
86 54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	54,000	46,000 ~~[illegible]~~	-04	-06
2	281,000	156,000		
3	422,000	199,000		
4	592,000	253,000		
5	12,000	22,000		

5

DATA LOG

Radiometer Measurements

Plane over at 12:34

Investigator____________________ Date 8-17-88

Time 12:30

9 m Depth ,089V/008 Temperature 19

High Voltage Setting 56/ 36
86 54

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	32,000	65000	-04	-06
2	163,000	127,000		
3	215,000	165,000		
4	350,000	213,000		
5	9,000	6700		

Depth ,089V/008 Temperature 19 HV Set 56/36
86 54

10m - (20inch)

botton

Filter Position	Mirror down Counts	Mirror up Counts	Pitch	Roll
1	32,000	64,000	-07	-04
2	168,000	120,000		
3	227,000	5,700		
4	308,000	5,700 ?		
5	7,600	6,000		

Station
1900

DATA LOG

Radiometer Measurements

Investigator ____________

Date 8-17-83

Time 12153

ack on
surface
at
ation
1900

Depth ·000✓/000

Temperature 22

High Voltage Setting 56/

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll
1	368,000		-03	-10
2	885,000			
3				
4				
5				

Depth ____________

Temperature ____________

HV Set ____________

	Mirror down	Mirror up		
Filter Position	Counts	Counts	Pitch	Roll

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19 ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Coastal Hydrographics Techniques (CHT) personnel in support of the Airborne Bathymetry System (ABS) traveled on two separate occasions to the CERC FRF at Duck, N. C., to provide ground truth data for the overflights of the system.

The following data report gives a preliminary look at the data and provides some preliminary analysis and simple calculations using the collected data for both CHT and ABS applications.

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