Lawrence Berkeley National Laboratory

Title
USE OF MONITORING DATA FROM OTEC SITES IN PREDICTIVE MODELS

Permalink
https://escholarship.org/uc/item/5w54q7ng

Author
Wilde, Pat.

Publication Date
1980-06-01

USE OF MONITORING DATA FROM OTEC SITES
IN PREDICTIVE MODELS

P. Wilde

June 1980

For Reference

Not to be taken from this room

DISCLAIMER

Use of Monitoring Data from OTEC Sites in Predictive Models

P. Wilde

Marine Sciences Group
Lawrence Berkeley Laboratory

Besides the conventional display of parametric data in tabular form, the following figures represent an initial attempt to display data, collected for, or useful to, the OTEC project graphically as a function of depth of water. Graphic display of data is recommended not only because it best portrays, the interrelationships among various parameters, but also because secondarily by the use of a temperature salinity diagram contoured in a third parameter (for example SIG-T where SIG-T = (density -1) x 1000); one may estimate the simple mixing of water from various depths in any proportion. This facility is extremely useful for designers and engineers as well as environmentalists as the first order effects of any proposed depth of the intakes and discharges mixed in any proportion may be determined.

Presently the parameters plotted on individual graphs are:

o   Classic Oceanographic Data: Figure 1

    Temperature: TEMP
    Salinity: SAL
    Density: SIG-T
    Dissolved
     Oxygen: DO

o   Nutrients: Figure 2

    Phosphate: PHO
    Nitrate: NIT
    Silica: SIL

o   Biologic Pigments: Figure 3a, 3b,

    Chlorophyll a: CHL a
    Phaeophytin: PHAEO
    Adenosine
     Triphosphate: ATP

o   Metals: Figure 4

    Zinc: Zn
    Copper: Cu
    Lead: Pb
    Cadmium: Cd
    Nickel: Ni

In addition, density and dissolved oxygen are plotted on all

graphs. As the OTEC measurement and monitoring program is expanded more parameters amenable to plots with depth will be graphed in this manner.

Calculation of Simple Mixing

Fundamental oceanographic parameters, temperature and salinity, are usually measured with each water sample. Thus, density, as a function of temperature and salinity, can be calculated for these samples, either (1) by plotting temperature and salinity on a graph on which density as SIG-T is contoured and extrapolating between the contour lines (figure 5) or (2) solving the equation of SIG-T (Cox and others 1970, p. 686). Either method can yield the values of SIG-T that are plotted on Figures 1 to 4. Figure 5 is the classic T-S diagram. Connected temperature-salinity points for each depth give a characteristic T-S profile for each station. From this profile simple mixing may be estimated by drawing a straight line between the two mixing depths and dividing the line proportionally. The relative distance along the connecting line would give the SIG-T value of a mixture of water from the two depths in that proportion. For example, a point 1/10th of the distance from the deepest end point would yield, on a SIG-T contour, the SIG-T value of a mixture of 10% water from the shallowest sample and 90% water from the deepest sample. A point midway along the connecting line would yield the SIG-T value of a 50-50 mixture. Defant (1961, p.202-218) gives a detailed discussion of the use of T-S diagram for mixing calculations. Use of T-S profiles in environmental studies in the ocean also is discussed by Amos and others (1972).

Density is not the only parameter whose mixture value can be determined by a contoured plot on a temperature-salinity diagram. Any useful parameter that is a function of temperature and salinity may be contoured. Table 1 lists some appropriate parameters of potential value to OTEC designers, etc.

Table 1

Sea Water Parameters as Functions of Temperature and Salinity

Parameter	Reference
Chlorine Equilibria	Sugam and Helg (1975)
Enthalpy	Connors (1970, p. 592)
Nitrogen Solubility	Weiss (1970, p. 726-728)
Oxygen Solubility	Weiss (1970, p.726-728)
Heat Capacity	Connors (1970, p.592)
	Millero and others (1973, p.4505)
Mean Compressibility	Ekman (1908)
Osmotic Pressure	Thompson (1932, p.84-85)
Adiabatic Temperature Gradient	Bryden (1973, p.404)
Carbonate Equilibria	Edmond and Gieskes (1970)
Carbon Dioxide Solubility	Edmond and Gieskes (1970)
Speed of Sound	Wilson (1960)
Thermal Expansion	Bryden (1973, p.402)

Example

To demonstrate the utility of plotting environmental data as in Figures 1-5, an example is discussed below using real data collected for OTEC background studies at the New Orleans site 29°N 88°W.

Problem: Assess the effects of various mixtures discharged at various depths.

Given: Intake Evaporator at 30 meters
         Intake Condenser at 1000 meters

Assume: 2° degradation of temperature through heat exchanger (EDP, 1977 p.5)

Procedure

(1) On Figure 5 (T-S plot) keeping salinity constant reduce the temperature 2° C for the evaporator side (28.3 to 26/3°C) and increase the temperature 2°C for the condenser side (4.82 to 6.83°C). This is done simply by drawing lines parallel to the temperature axis through the points at 30 and 1000 meters and marking off the appropriate 2°C temperature change using the scale on the left.

(2) Connect the new end points with a straight line. Positions along this line will yield the density value of any proportional mix.

Case I - 1:1 mixture of evaporator discharge and condenser discharge.

(3) On Fig. 5 find the midpoint along the mixing line (1:1 mix). This gives a SIG-T = 26.2 which is the density of the mixture.

(4) On Fig. 1 plot SIG-T of 26.2. The ambient density of this value is at 140 meters. This would be the equilibrium depth of the mixture. Thus, a discharge below 140 meters would rise and a discharge above 140 meters would sink. Because 140 meters is in a strong pycnocline, discharges significantly above or below the equilibrium depth would mix well before reaching the equilibrium depth.

For parameters essentially independent in value of either temperature or salinity a 1:1 mixture may be approximated by the mean value of the value at 30 and 1000 meters or:

    mean DO = 5.07 ml/l
    mean PHO = 0.9 ugmAt/l
    mean NIT = 14.4 ugmAT/l

For the metals of Fig. 4, insufficient data has been taken in the Gulf of Mexico to justify the use of a mean value as the composition of the mixture. However, when sufficient data is taken at enough depths the same procedure could be used to determine the equivalent ambient depths. Based on previous metal studies elsewhere it is expected that the metals, except right at the surface for aerosol metals like Pb,

should have curves of a similar shape to the nutrient curves of NIT and PHO. Figure 4 is given here as an example of expected range of values and shows initial values collected.

For biologic parameters of Fig. 3 such as CHL <u>A</u>, PHAEO and ATP, that indicate in-situ living conditions, mean values or mixture values would have no significance. However, the profiles are useful as will be shown.

(5) Plot these mean values on Figure 2. The intersection of these values with the appropriate curves gives the equivalent ambient depth (EAD) or the depth at which they may be discharged with no change compared to the ambient value. Unfortunately as one can see by inspection, the various EADS are not the same. Thus, it is impossible to pick a discharge depth which produces minimal environmental impact for all parameters. From the shapes of the curves it is seen that for:

o   DO: A discharge above 105 M would cause local depletion of DO while that below would locally enhance the dissolved oxygen content.

o   NIT: A discharge above 342 M would enhance the local nitrate budget.

o   PHO: A discharge above 260 M would enhance the local phosphate budget.

Analysis

If the discharge is in the photic zone PHO and NIT may be used to produce photosynthesizing organisms and oxygen generated as modeled by the Plankton Equation (Richards, 1965).

$$106 \ CO_2 + 122 \ H_2O + 16 \ HNO_3 \rightarrow [(CH_2O)_{106}(NH_3)_{16}H_3PO_4] + 138 \ O_2$$
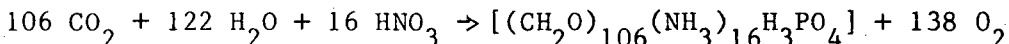
As the ratio of NIT/PHO in the mixture is the appropriate 16:1 (14.4:0.9) a discharge in the photic zone could yield as a maximum 0.9 ugmAT/l plankton or

$$0.9 \times 10^{-6} \ \text{atoms} \times 3.550 \times 10^3 \ \text{gms/atoms} = 3.2 \times 10^{-3} \ \text{gm/l plankton}$$

and generating

$$138 \times .9 \times 10^{-6} \ \text{atoms} \times 32 \ \text{gms/atoms} = 3 \ \text{mgm/l} = 2.1 \ \text{ml/l} \ )_2$$

For a projected flow through a commercial OTEC plant of 6×10^{10} liters per day (EDP, 1977, p.14) the maximum plankton potential would be

19.2×10^7 grams/day   or
19.2×10^4 kilograms/day or
6.9×10^4 kilogram C/day

This figure assumes all the nutrients would be converted to organic matter essentially instantaneously before being mixed to lower

concentrations with near-surface low nutrient water. The maximum figure would be the equivalent, using the average marine primary production as 0.51 gm C per m^2 per day (Nielsen and Jensen in Fogg, 1976, p. 442), of the daily production of an area 135.3 Km^2 kilometers or a radius of 6.6 Km kilometers around the plant. Obviously the actual value would be less because light is only available in the tropics one-half the day and the rate of primary production is governed by many environmental factors besides nutrient concentration (Fogg, 1976). The rate and effective primary productivity due to mixing is being studied using C^{14} uptake methods.

Increased nutrients add to the bio-fouling problem, particularly if the discharge is entrained back into the evaporator intake, and has the potential to create a noxious "red-tide" condition. It therefore seems advisable to discharge below the photic zone and leave the nutrients as dissolved species to be thoroughly mixed with ambient water.

The actual depth of the photic zone could be determined by a combination of ambient light measurement and detailed pigment and C^{14} uptake studies. However, the effective depth of primary productivity may be estimated by inspection of the shapes of the DO, PHO, and NIT curves of Figure 2. The subsurface maximum of DO is at 50 meters indicating maximum primary productivity. This is substantiated by the low values of PHO and NIT because the nutrients are in living organisms. Below the oxygen subsurface maximum the oxygen values decline and the nutrient values increase at the maximum observed rate. This shows that the decay of organic matter raining down through the water column is dominant over organic production and oxygen is used to oxidize the organic matter releasing dissolved nutrients.

An indication of the profile of primary production is shown in Figure 3 where CHL a maximum is at 30 meters, declining rapidly below that depth. This also matches a secondary maximum in ATP which gives an indication of the amount of total living material. Thus, a conservative estimate of the depth of the photic zone would be below the subsurface oxygen maximum and CHL a maximum, in the zone of maximum slope of the nutrient and oxygen curves and where the CHL a values stabilize at a low value at about 100 meters. Accordingly, a discharge below 100 meters would greatly reduce the chance of bio-stimulation, and would have the advantage of having an effluent with an oxygen content apparently higher than ambient regardless of any excess oxygen produced by primary production.

However, an unknown factor at this time which would affect the DO values is the amount of dead oganic matter produced by entrainment/impingement at the intakes. Such material would have an oxidative decay demand on the oxygen in the mixture as well as in the ambient water near the discharge point. This is shown in the decay or remineralization direction of the Plankton Equation. Depletion of oxygen particularly to low or anoxic values might have deleterious effects on any oxygen breathing organisms living near or migrating vertically through the discharge depth. The major amount of entrained organisms and organic matter may be reduced by placing the intake as close to the surface as possible in tropic waters. By inspection of Figure 5, it is

seen that changing the evaporator intake to the surface would only increase the equilibrium depth by 20 meters to 120 meters would actually increase the operating ΔT 1.3°C, and would not affect substantially the mixing values of DO, PHO and NIT.

To determine the amount of potentially oxidizable material additional data is required, for example particulate organic carbon (POC), dissolved organic carbon (DOC), biomass, etc. as functions of depth. Measurement of these parameters on an experimental basis is planned in the forthcoming baseline studies at the OTEC benchmark sites.

It is unlikely that any mixed discharge practically could be placed, except at high energy cost, much below the equilibrium depth of either 120 or 140 meters because of the positive buoyancy of the mixed effluent below these depths. A discharge at the base of the photic zone at 100 M would be negatively buoyant but would have the advantage of entraining more oxygen rich water before mixing than would a discharge at the equilibrium depth which is at the secondary oxygen minimum. This would tend to alleviate any oxygen demand problem caused by dead organic matter. Also, because the discharge is below the photic zone, any increased PHO or NIT released by decay would not cause biostimulation.

Summary

Based on available data at one proposed OTEC site used as an example, simple graphic displays show how the relationships among various physical, chemical and biological parameters can be examined quickly and first order effects of design discharge depths can be determined. Obviously for real design or environmental studies, serial and seasonal data must be used. However, the approach would be the same except that each parameter would plot as an envelope showing the range of values, the worse case profile, or the most expected profile. Other profiles showing parameters such as geostrophic currents, measured currents, biomass, etc., would be useful in refining any first order decision and in developing any higher order models.

Glossary

ATP - Adenosine triphosphate is a biochemical compound used by cells. ATP values are used to give estimations of microbial mass.

Chlorophyll a - A pigment which acts as a catalyst in photosynthesis Because it is found in all photosynthesizing plant matter, such as phytoplankton, it's measurement is a convenient method of determining phytoplankton biomass. Its concentration can be measured using a spectrophotometer.

Equilibrium Depth - Depth in the ambient ocean which has the same density as proposed mixture of waters from various depths. Depth which any discharged mixture would seek.

Equivalent Ambient Depth - Depth in ambient ocean which has the same value as any non-conservative mixture could be introduced without changing the ambient value. Depending upon parameter, could be a multiple depths.

Model Plankton - Generalized phytoplankton composition used in productivity/decay equations as a chemical compound.

$$[(CH_2O)_{106}(NH_3)_{16}(H_3PO_4)].$$
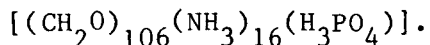
Molecular weight = 3550
% carbon = 36%

Phaeophytin - The degradation product of chlorophyll when a magnesium atom is lost from the (photosynthesis) pigment molecule. Like chlorophyll pigments its concentration can be measured using a spectrophotometer.

Photic Zone - Region in the upper ocean to which light penetration could cause photosynthesis if proper nutrient conditions are met.

Pycnocline - Area in the ocean where density changes most rapidly with depth. Thus, it is a region of strongest density stratification. Analogous to the thermocline.

SIG - T - Oceanographic Density of Sea Water = (Density in gm/cm^2-) x
1000

T-S Curve - For any given hydrogapic station a plot of temperature and salinity values for each sampled depth on a T-S diagram. A curve connecting the depth in sequence gives a signature which may be used to identify water masses and for calculating mixing of waters from any depth in any proportion.

T-S Diagram - Temperature-salinity diagram on which SIT-T is plotted, used to easily and visually plot density.

References

Amos, A.F., C. Garside, K.C. Haines and O.A. Roels, 1972. Effects of surface discharged deep-sea mining effluent. Mar. Tech. Soc. Jour., v.6, No. 4, p.40-45.

Bryden, H.L., 1973. New polynomials for thermal expansion, adiabatic temperature gradient and potential temperature of sea water. Deep-Sea Res. v.20, p.401-408.

Connors, D.N., 1970. On the enthalpy of sea water. Limnol. Oceano. v.15, p. 587-594.

Cox, R.A., M.H. McCartney, and F. Culkin, 1970. The specific gravity/salinity/temperature relationship in natural sea water. Deep Sea Res. v. 17, p. 679-689.

Defant, A., 1961. Physical Oceanography, Chap. VI, The (T-S)-relationship and its connection with mixing processes and large water masses. London, Pergmamon, v.I. p.202-218.

Edmond, J.M. and J.M.T.M. Gieskes, 1970. On the calculation of the degree of saturation of sea water with respect to calcium carbonate under in situ conditions. Geochim. Cosmochim. Acta. v.34, p.1261-1291.

Ekman, v.W., 1908. Die Zusammendruekbar-Keit des Meerwassers. Conseil perm. Intern. Expl. de la Mer., Pub de Circonstance, no. 43, 47 p.

Fogg, G.E., 1975. Primary Productivity. In Chemical Oceanography, v.2., Riley and Skirrow (eds). 2nd edition. London Academic Press. p.385-453.

Miller, F.J., L.D. Hansen, and E.V. Hoff, 1973. The enthalpy of sea water from 0 to $30^{\circ}C$ and $40^{\circ}/_{oo}$ salinity. Jour. Mar. Res. v. 31, p.21-39.

Richards, 1975. Anoxic basins and fjords in Chemical Oceanography, Riley and Skirrow (eds): London, Academic Press, V.1 First edition, p. 611-645.

Sugam, R. and G.R. Helz, 1975. The apparent ionization constant of hypochlorous acid in marine and estuarine systems. EOS, v.56, no.6, p.373.

Thompson T.G., 1932. Physical properties of sea water in physics of the earth. v.5, Oceanography: U.S. Nat. Res. Council, Bull. 85 p. 63-94

U.S. Department of Energy, 1977. Environmental Development Plan (EDP) Ocean Thermal Energy Conversion: US Govt. Printing Office, Wash. DC 48 p.

Weiss, R.F., 1970. The solubility of nitrogen, oxygen and argon in water and seawater. Deep Sea Res. v.17, p.721-735.

Wilson, W.D., 1960. Calculation of the speed of sound in sea water. J. Acoust. Soc. America, v.32, p.1357.

PHYSICAL OCEANOGRAPHIC PARAMETERS

Temperature, Salinity, Dissolved Oxygen, Sigma-T

GOTEC-OI, Station 25, Mobile site, 28° 58.3'N, 87° 58.3'W
21 July 1977, 1700 h EDT (202:21:00Z)
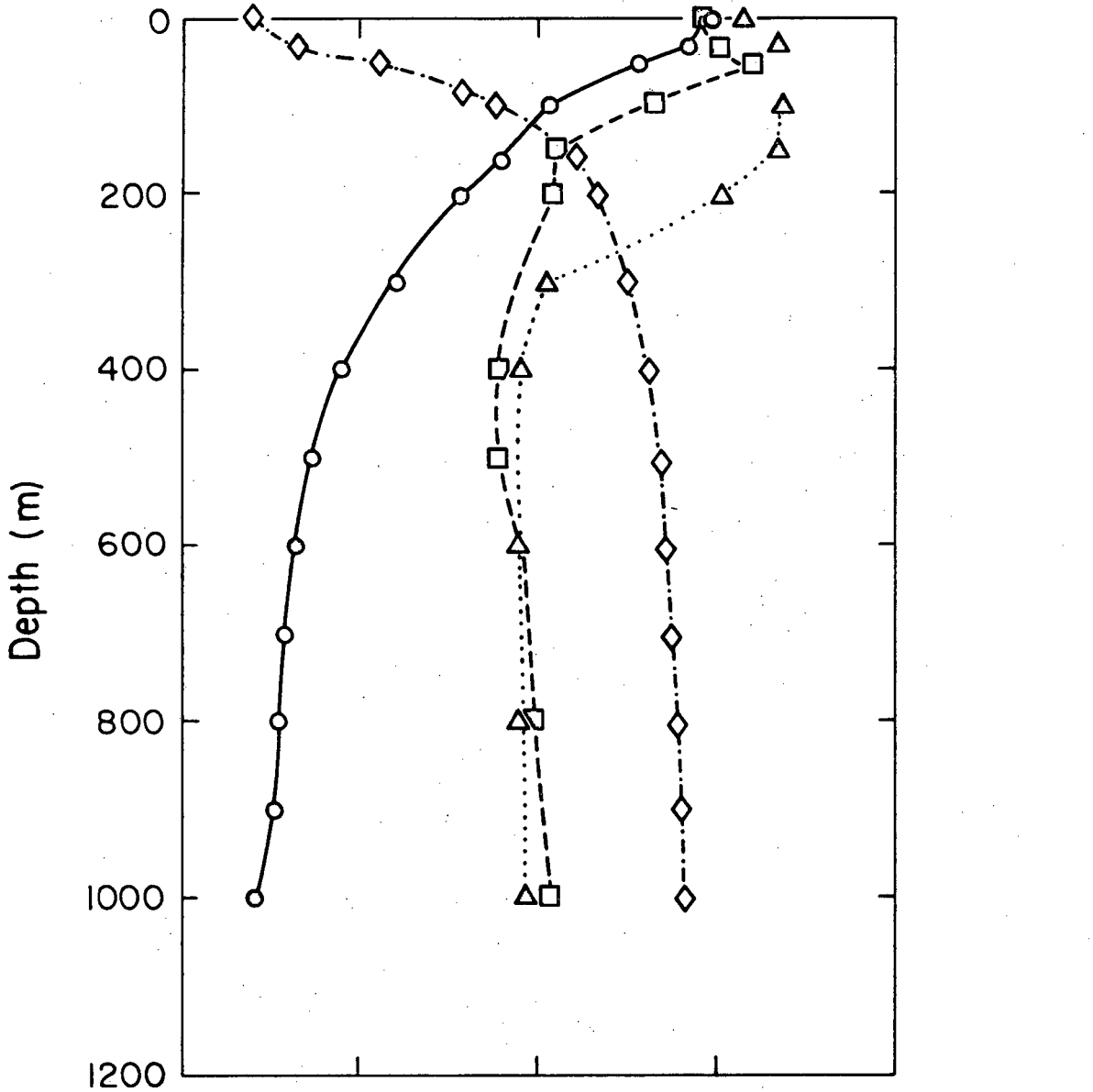
Temp.*(°C)	0	10	20	30	40	o ——
Sal.*(‰)	33	34	35	36	37	△ ········
D.O. (ml/l)	0	2	4	6	8	□ -----
Sigma T[†]	22	24	26	28	30	◇ ----

*Curve partially constructed from STD data.
Symbols for STD data points were : Temp. – o , Sal.- △
[†] From STD data

FIGURE 1.

XBL 794-1168

NUTRIENT DATA
Dissolved Oxygen, Nitrates, Phosphates

GOTEC-01, Station 25, Mobile site, 28° 58.3'N, 87° 59.8'W
21 July 1977, 1700 h EDT (202: 21: 00Z)

D.O.(ml/ℓ)	2	4	6	8	o ——
Nitrates (μg-at/ℓ)	10	20	30	40	△ ----
Phosphates (μg-at/ℓ)	0.5	1.0	1.5	2.0	▢ ······
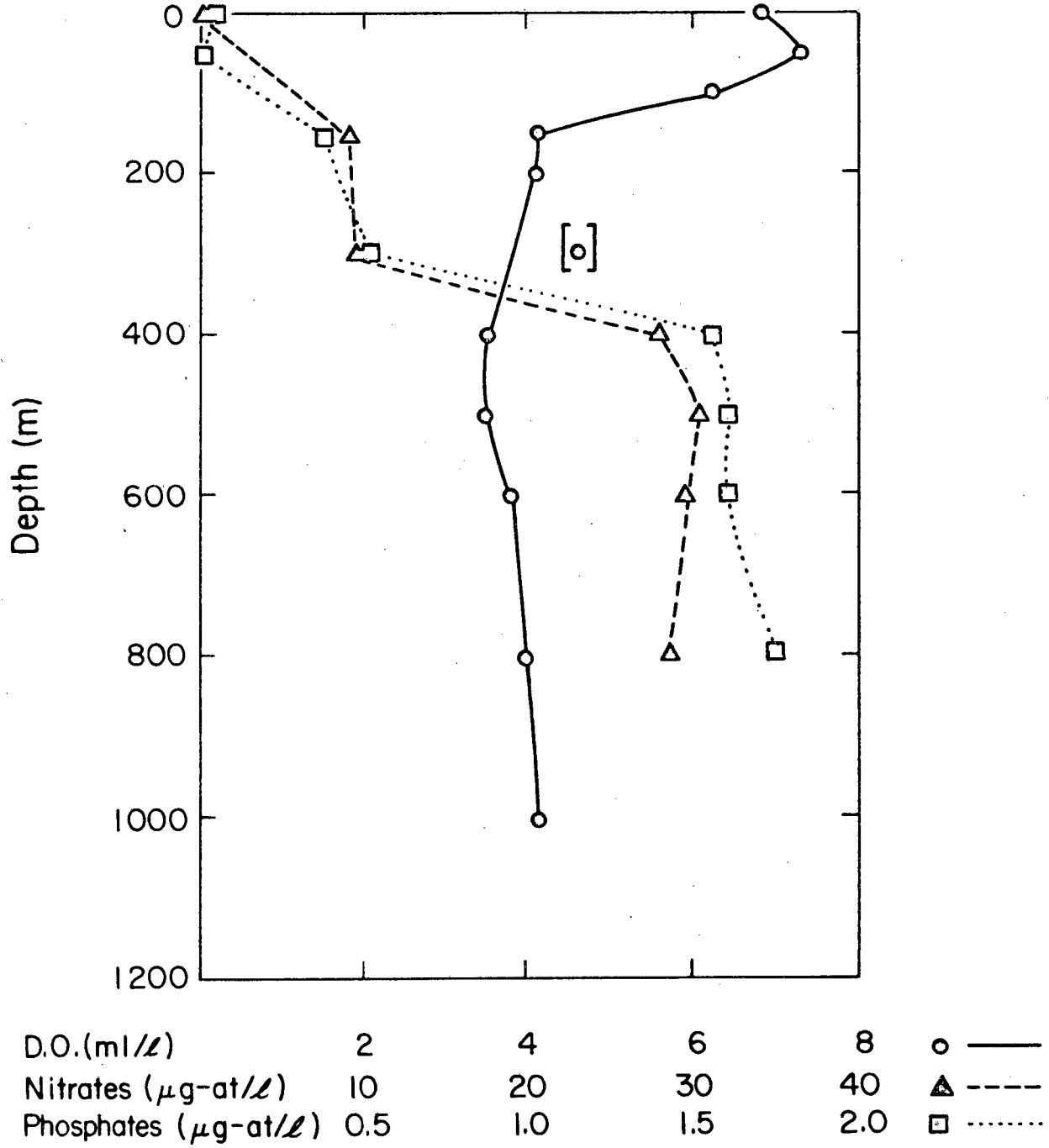
[o] -*Points in brackets indicate questionable results*

FIGURE 2.

XBL 794-1184

BIOLOGICAL PIGMENT DATA
CHLOROPHYLL a

GOTEC-01, Station 11, Mobile site, 29°02.3'N, 88°01.9'W
18 July 1977, 1700 h EDT (199:21:00Z)

CHL a (μg/ℓ)   0.1   0.2   0.3   0.4   o ———
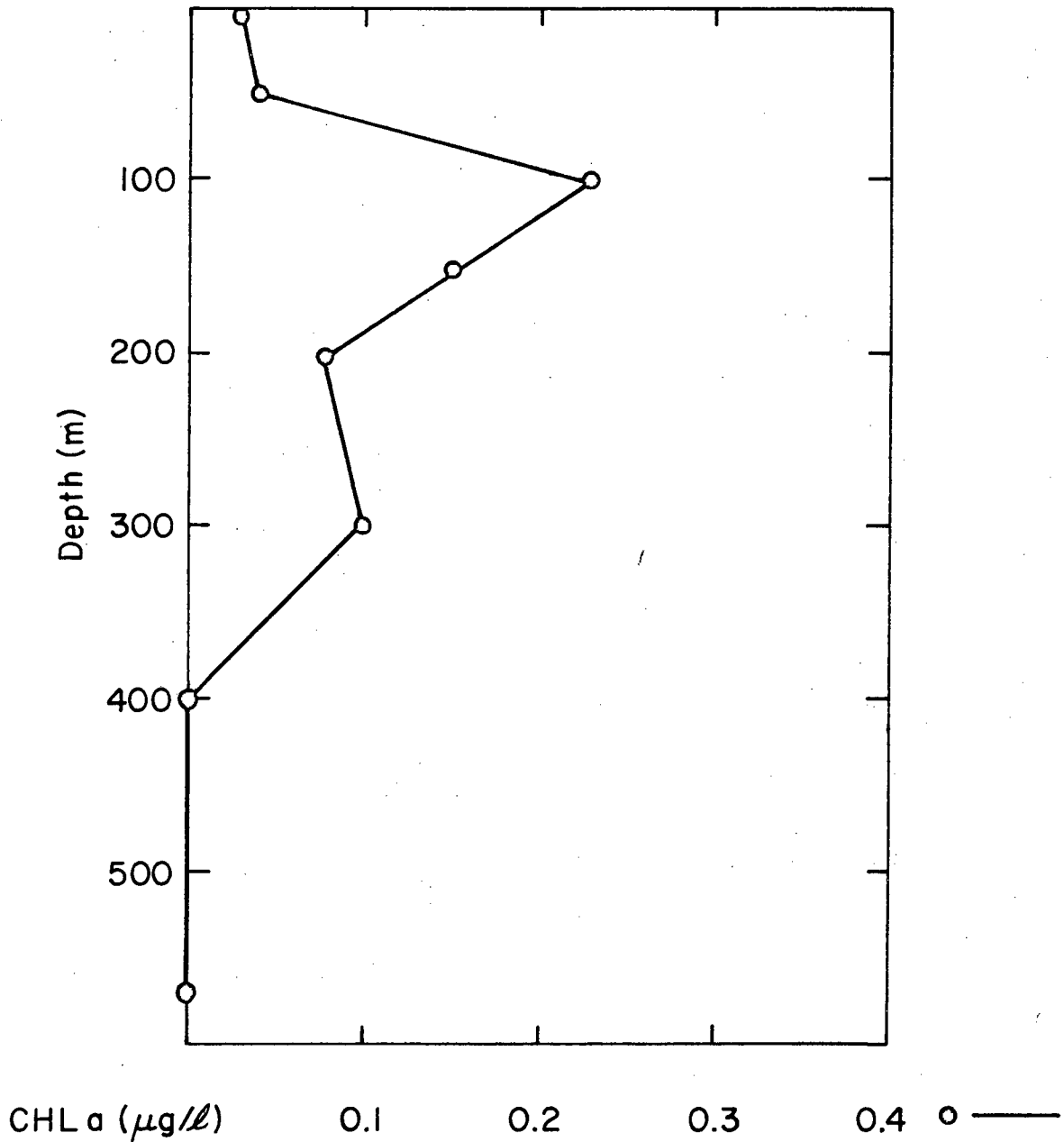
FIGURE 3a.   XBL 794-1174

BIOLOGICAL PIGMENT DATA
ADENOSINE TRIPHOSPHATE

GOTEC-OI, Station 25, Mobile site, 28°58.3'N, 87°59.8'W
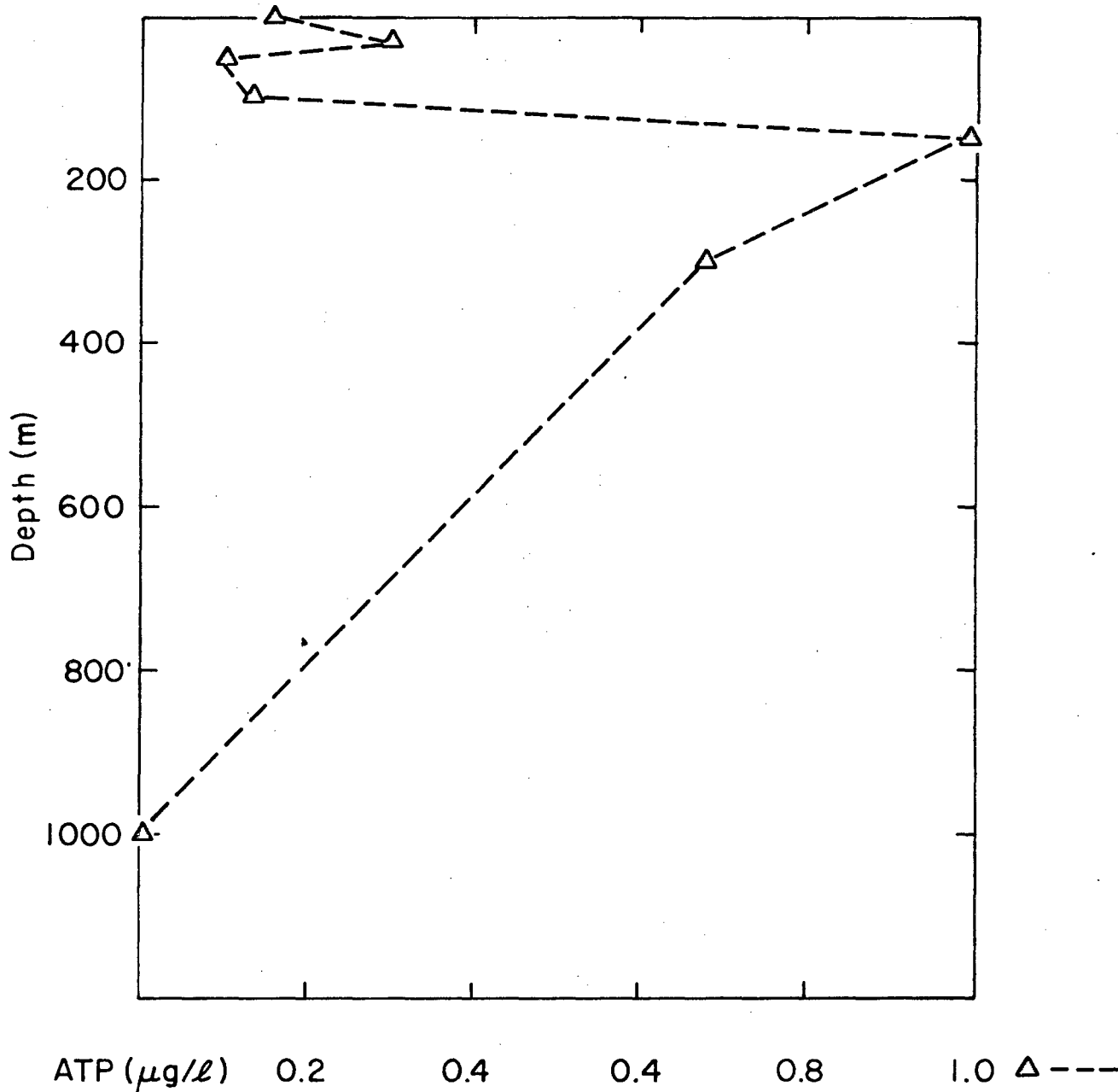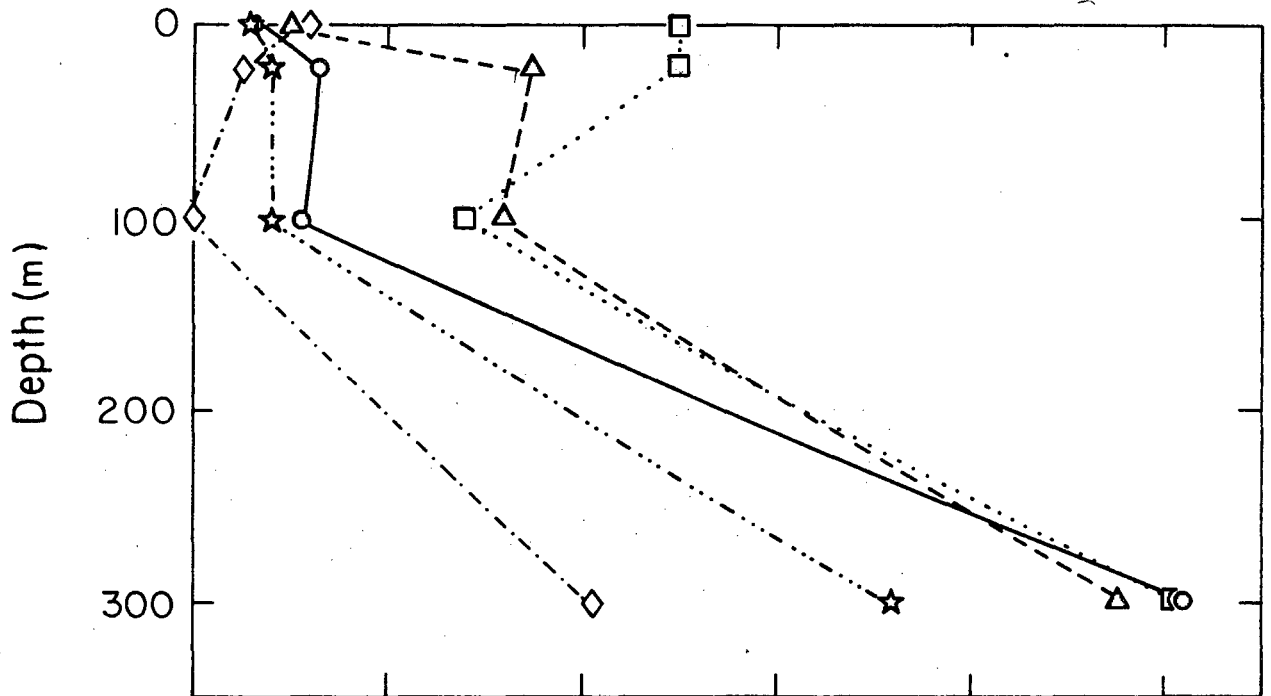21 July 1977, 1700 h EDT (202:21:00Z)

FIGURE 3b.

XBL 794-1177

TRACE METALS
Cadmium, Copper, Nickel, Lead, Zinc

GOTEC-01, Station 24, Mobile site, 29° 06.4'N, 87°58.8'W
21 July 1977, 1325 h EDT (202:17:25Z) on deck

Cd (ng/ℓ)	10	20	30	40	50 o —
Cu (μg/ℓ)	0.04	0.08	0.12	0.16	0.2 △---
Ni (μg/ℓ)	0.1	0.2	0.3	0.4	0.5 □·····
Pb (μg/ℓ)	0.2	0.4	0.6	0.8	1.0 ◇-·-·
Zn (μg/ℓ)	1.0	2.0	3.0	4.0	5.0 ☆-··-··

FIGURE 4.

XBL 794-1186

DENSITY AS SIGMA T((G/CM³)-1)x1000

FIGURE 5.