DEPTH OF SENSORS FIXED TO A TOWED CHAIN

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Abstract

One important piece of scientific equipment now in use on oceanographic research vessels is the thermal-tow, an instrument which utilizes a faired cable (267 meters long on the Texas A&M University vessel ALAMINOS) with thermistors attached at 7.6 meter intervals and with a pressure (or depth) transducer at the end of the chain. The cable may be towed at speeds up to approximately ten knots and data are recorded automatically in several forms in the ship laboratory. As ship speed, wind, ocean current, sea state and other conditions change, the depth attained by the 267 meter cable changes. Thus, the thermistors (or other sensors) affixed to the chain also change depth and a way must be found to determine the depth at which each is functioning. On ALAMINOS Cruise 64-A-7, May, 1964, data were collected from which a depth determination chart was developed. The nature of this chart and its practical application are the subject of this presentation. In brief, the chart is a set of scales such that, given the depth reading from the chain end, the depth associated with any particular point along the chain length may be read off.

Text

INTRODUCTION

Thermal-tow data are transmitted to the ship laboratory where, on the ALAMINOS, temperature is recorded in several ways: on punched tape, in typewritten form, and as isotherms on a contour chart having chain length and time as coordinates. Temperatures at selected thermistors may also be read from indicating dials. Chain-end depth is recorded on the contour chart and also shown on a depth dial. Instruments somewhat similar to this thermal-tow have been described by Richardson and Hubbard, 1960, and by La Fond, 1962.

As mentioned, variations in environmental conditions affect the depth attained by the 267 meter cable. Thus, the depths of thermistors (or any other sensors) affixed to the chain also change and the problem arises of determining the depth at which each is recording. On ALAMINOS cruise 64-A-7, it was hoped that the depth of the thermistors could be held constant by keeping the ship's engines turning at a constant number of revolutions and thus keeping constant the speed of the ship relative to the water. However, the pressure transducer attached to the lower end of the chain showed depths from 185 to 243 meters with constant engine speeds of 580 revolutions. The indicated depth changes were not random but occurred many times with noticeable changes in environmental conditions.

On cruise 64-A-7 there were fairly long periods when conditions were relatively constant and when the chain depth did not change materially. For example, from 0546 GMT on May 20 to 1100 GMT on May 21, the chain depth as indicated by the transducer at its end varied only between 209 meters and 220 meters. During this period the speeds of the ship's engines were maintained at 580 revolutions and the ship was travelling northward beginning at the southen end of Leg VI of the cruise, see Fig. 1. The track of Leg VI was chosen as one along which there was a minimum of ocean current to be expected at the southern end. The minimal slope in the observed isotherms indicated that this was actually the case. Thus, the effects of currents on the chain were small, and the vertical migrations of the chain were limited.

The shape of a towed chain is complex. When a current does exist the shape may change not only in the vertical plane in which the ship is moving but in the third dimension also, as when the ship is travelling across the current system. The nature of the cable and its surface position when the ship is underway is shown in Fig. 2.

GENERAL OBJECTIVE FOR DEPTH RANGE

For practical reasons it seems desirable to tow the instrumented chain at a speed which allows it to attain a depth greater than 200 meters. This provides information throughout the layer in which most of the seasonal effects on temperature, other than those related to the general circulation, are observed. It permits the deepest values to be related to such data as those in the Atlas of Temperature at a Depth of 200 Meters, Schroeder, 1963, and permits the full set of data to be used in forecasting sea temperatures in a manner similar to that indicated by Iselin, 1964. It provides temperatures for comparison with those obtained using the deep bathythermograph. Finally, it requires that the ship speed be low enough that there is no more than a reasonable amount of turbulence near the chain, and yet it allows the ship to travel at some six to nine knots.

After an initial period of experience on cruise 64-A-7 the engines on the ALAMINOS were turned at a number of revolutions such that the pressure transducer attached to the chain end varied in depth between about 215 and 225 meters. Engine speeds were changed as few times as possible as long as the chain end could be kept within this range.

MEASUREMENT OF DEPTH

At the beginning of cruise 64-A-7, it was planned to put but little dependence upon the depth readings obtained from the pressure transducer. However, as the cruise proceeded the behaviour of the transducer was seen to be closely related to observed environmental factors. The various other methods considered for depth determination showed themselves to be difficult and questionable, and more and more reliance was placed upon the chain-end transducer. Before the cruise ended, the transducer readings were being accepted as correct and other considerations were used only to supplement the transducer information. In the depth determination method finally adopted, the transducer reading at the time of observation determines the depth scale with which the isotherm depth is read from the contour chart for that observation.

THE CONTOUR CHART

The nature of the contour chart, Fig. 3, plays an important role in the establishment of a method for depth determination. On this chart the horizontal scale indicates time with 15 inches being an hour at the setting used on cruise 64-A-7. When the ship is underway at a given speed, this scale also represents distance.

The depth or vertical range on the contour chart paper extends 14 inches. Since the vertical scale is a linear scale of chain length, each thermistor on the chain is represented by the temperature value at a fixed vertical position on the chart, regardless of the depth of the thermistor in the water. The surface thermistor records at the top of the vertical scale and the deepest one records 14 inches lower at the bottom of the sheet. The intermediate thermistors are equally spaced along the chain and the isotherms, which are linearly interpolated between thermistors, appear at the proper proportionate distances along the chain between the surface and bottom thermistors. Since there are 32 equally spaced thermistors, the positions at which they are effective on the vertical scale of the contour chart are 14/31 inches apart vertically. A coded scale may be prepared showing which thermistor is at each position. Since dial temperature readings may be obtained for several thermistors, these readings may be entered on the contour chart and used as a basis for labelling the isotherms on the contour chart.

Since each thermistor is represented by the temperature value at a fixed vertical position on the contour chart, the linearly interpolated isotherms appear so that, whatever the total depth range of measurement by the chain may be, the full depth extent of the associated temperature field is equal to 14 inches on the contour chart. Thus, when the ALAMINOS is drifting and the chain is hanging vertically, 14 inches represents 267 meters of depth. The vertical scale then is linear in depth as well as in chain length since, under these circumstances the chain, for all practical purposes, hangs vertically due to its weight of some 6300 pounds. When the ship gets underway the chain will drag and its lower end will come to a shallower depth. At some eight knots the chain end will be at about 220 meters depth. At this time the 14 inches on the chart will represent 220 meters and the scale, although still linear in chain length, will no longer be linear in depth if there is curvature in the chain.

It does appear that curvature is introduced when the chain is under tow. As the chain end rises, the chain takes a catenary-like shape. The greatest curvature is at the bottom where the tension is least and the greatest deviation from the vertical is observed in the upper layers of the ocean. In these upper layers, because of the chain slope, the thermistors are at reduced true depth intervals from each other but they still are represented at the same vertical positions on the contour chart.

Thus, the isotherms on the contour chart appear at wider spacing in the upper layers as the ship speed is increased and the chain end rises. In the opposite case, as the chain end lowers, the isotherms in the shallow layers move together on the contour chart. Upon careful examination Fig. 3 illustrates this. This fact must be considered when studying the contour chart during a period when the depth of the end of the chain is varying.

Chain depth affects the isotherms appearing on the contour chart in other ways. As ship speed decreases the bottom of the chain falls deeper and isotherms not previously observed will be recorded on the lower portion of the contour chart. Also, all other isotherms on the chart will move upwards as the greater depth ranges covered by the descending chain must be compressed into the 14 inch vertical recording space on the chart. When the ship speed is increased a reverse change in position of isotherms occurs and each isotherm appears at a lower position (greater chain length) on the contour chart. Fig. 3 provides also an example of the change in isotherm position on the contour chart as ship speed changes.

DISCUSSION OF DEPTH DETERMINATION

It would seem logical that analytical approaches be the first to be tried. The simplest of these is the assumption that the chain is straight between the ocean surface and the chain-end depth. When the ship is drifting this is a good assumption as indicated for example by the fact that the depth reading from the transducer at the bottom of the chain is the same as the length of the chain. However, when the ship is underway and when the readings derived using the linear assumption are compared to the best data on true depth available from bathythermograph observations and from thermal-tow records made while the ship was drifting, there seems to be considerable deviation from linearity. Errors at the surface and at the lower end of the chain are zero by the nature of the linearity assumed. At intermediate depths the errors vary depending upon the total depth reached by the 267 meter chain. For the common chain-end depth of 220 meters the error due to use of the linear assumption apparently would be approximately 6 meters at 50 meters depth, 10 meters at 100, and 6 meters at 150. When the chain end is at shallower depths the error would be larger. With a chain-end depth of 180 meters the errors at the above three respective depths would be approximately 8, 16, and 9 meters. With the chain reaching deeper to 240 meters the corresponding errors would be less, being about 4, 6, and 3 meters respectively. Not only does the use of the linear assumption appear to give considerable error at intermediate depths but, when conditions are such that the end of the chain may rise and fall, the errors are systematic and distortions introduced on the contour chart as previously described go uncorrected.

A second and better analytical representation of the towed chain would be a catenary-like curve. Some idea of the complexity of the analytical approach in this case may be obtained by reference to Pode, 1951, Ellsworth, 1960, Thorne, Blackshaw and Claasen, 1962, and Claasen and Thorne, 1963. At the present time it would appear that this approach is not the most practical one for determining the depths of thermal-tow observations. There are two reasons. First, the difficulty of obtaining representative equations for the curve which take into account all of the pertinent variables, and second, the fact that certain of the assumptions which must be made are such that they do not apply well to the thermal-tow situation.

In obtaining representative equations the variables involved would be: 1) The drag characteristics of the faired-cable including the ratio of normal and tangential drag coefficients, 2) The relative speed of the ship, 3) The chain weight per unit length, (and total weight), and 4) The weight of the towed fish. Of these, the last two are readily available. The second could be obtained by observation, at least in-so-far as ship speed relative to surface water movement is concerned. The relative speed at the lower end of the chain would be more desirable but more difficult to obtain. The remaining set of variables, the drag characteristics, are not now available and could be obtained only through experiment. Without these, calculation of depth would be subject to large errors.

The effects of the above variables upon the shape and position of the chain are indicated by several observable features. Among these are the total tension at the tow point, the wire (or chain) angle, the depth of the chain-end, and the horizontal distance of the towed fish from the surface tow point. (Of these only the depth of the chain-end is available from cruise 64-A-7.) The wire angle may be computed at the surface from recorded data. Although they were not available on this cruise, it is possible that arrangements might be made for measuring the tension and the horizontal tow distance on future cruises. If this were done, these measurements would make it possible to deduce the drag characteristics of the chain and thus to compute depths analytically.

As to the applicability of the assumptions which are made in calculating the catenary-like curves, the greatest deviation in the case of the thermal-tow is probably that from the apparently universal assumption that the cable lies in a vertical plane parallel to the direction of the motion. If the ocean waters were not moving or if the ship moved only along the path of ocean currents this assumption might be valid. However, most oceanographic cruises are planned to measure the gradients of the different variables and these are nearly always perpendicular to the flow. For example, the gradient of density is at right angles to the common geostrophic flow. Thus, research vessels often move across the current and the flow of the waters acts to move the towed chain out of the vertical plane defined by the ship's path. Indications are that such cross currents in the Gulf of Mexico were responsible for vertical shifts of thermistors of 10 meters or more. The assumption of a plane curve parallel to the ship's motion is therefore not a good one for this application.

Usually assumed too is that "equilibrium conditions in a uniform stream" prevail. In actual practice, the thermal-tow may be used on long cruises encountering a wide variety of conditions and, as mentioned, the depth of the chain-end and thus the shape of the cable varies considerably, greatly weakening the applicability of this assumption.

Only after considerable effort to find a completely workable analytical approach to the determination of depth of isotherms was it decided that an empirical one would be more adaptable to the thermal-tow problem at the present time.

PREPARATION OF A DEPTH DETERMINATION AID

For practical use in determining the true depth of isotherms printed on the contour chart, a simple overlay scale of depth would be desirable. Thus, at any given time the depths could be read off. If the chain elements remained at fixed depths only one scale would be needed but, as previously described, the depths do change significantly. The chain-end depth is the most readily available indicator of these changes. Therefore, this quantity provides a good index of depth scales to be used. It is convenient to assume that for a given chain-end depth there is only one definite shape and position of the chain. Under this assumption, which seems applicable in many situations, a large number of empirical depth scales might be made up, one for each value of the chain-end depth. However, it is more convenient to place these scales side by side and to prepare from them a graph which would serve for any value of the chain-end depth.

In constructing such a graph, use is made of the following terms:

L - the total length of cable submerged
h - the depth of the chain-end
z - the depth below the surface at which a temperature is measured or interpolated
s - the cable length below the surface required to reach the depth z.

Consider on rectangular coordinates a graph where h is the abscissa with a range from 0 to L and where s is the ordinate with range 0 to L. See Figure 4. On this figure several relationships may be indicated. First, $z = s$ when $h = L$ since under these circumstances the chain must be hanging vertically. Further, $z = h$ when $s = L$, $z = 0$ when $s = 0$ and $z = 0$ when $h = 0$. These facts, used together with the concept that the greatest curvature must occur at points where tension is least, permit the general character of lines of constant z to be determined.

In Figure 4 the line indicated z_1 is drawn to show the nature of the z contours when the conditions are approached where $z = 0$ when $s = 0$ and where $z = 0$ when $h = 0$. On the lower right-hand portion of the chart the line indicated z_n connects equal values of z and probably does not deviate significantly from a straight line. The lines indicated by z_{50} and z_{100} must join equal values of z on the right hand and bottom scales, 50 and 100 m respectively, because of conditions noted above. Their slopes would be intermediate between the slopes of line z_1 and line z_n- somewhat as indicated.

Since on cruise 64-A-7 the range of h was limited between 180 meters and 267 meters and since the chain-end will usually be kept below 180 meters, attention may be confined to that range. Figure 5 has been drawn to cover this range only. Within this range the field of z was plotted from field data in the following manner:

First, at a given ship position the true depth of each isotherm was determined. This was done by allowing the ship to drift so that the chain would hang vertically and s would equal z. The depth could then be read off the contour chart since, as above, s and z are equal under these circumstances. The depth of isotherms or other values of temperature at this ship position could be checked in other ways as with a deep bathythermograph or with a hydrographic cast.

Next, to determine a depth scale for use at a particular chain position, the ship's engines were started and the chain-end came up to a new and shallower depth h_n. The assumption was made that the isotherms in the ocean remained at the same depth over a short period of time (roughly 15 minutes) and within a limited area (a 2-mile radius) of the position where the drifting observation was made. This assumption can be checked by observation when it seems desirable to do so. Since the chain moved vertically when the ship got underway and since the contour chart is drawn using a vertical scale of chain length, the isotherms with the ship underway appear at different vertical positions on the chart than they did when the ship was drifting. Now, each new vertical position has associated with it a true depth z for the particular isotherm or temperature value which appears there, this depth being the one observed for that isotherm or temperature value while the ship was drifting. These values of z may be entered along the vertical scale of the contour chart beside the appropriate value of s where the pertinent isotherm is found when the ship is underway. This vertical set of values of z defines a depth scale which applies for the particular chain position associated with that ship speed and designated by that chain end depth h_n.

In a similar fashion depth scales were prepared for other chain positions indicated by other values of h. The data were obtained by going from the ship drifting situation to different underway ship speeds, bringing about different chain-end depths for comparison. The depth or z scales obtained in this way for the various values of h were then transferred to Figure 5 and plotted along the ordinate having the appropriate value of h. These plotted values indicate the field of z on the h, s coordinates.

Recalling the general features required of lines of equal z value as indicated on Figure 4 and observing the data in Figure 5 it is apparent that, over the range of h covered in Figure 5, the curves of equal value of z may be assumed to be straight lines to a good approximation. Thus, such lines were drawn to fit the data and to satisfy the general criteria previously mentioned. These are the sloping lines in Figure 5 which are marked with values of z.

Finally, to simplify the depth determination chart, the s scale and grid lines were removed since no reference to them need be made in application of the chart. The depth determination graph of Figure 6 resulted.

The manner in which Figure 6 was prepared is such as to incorporate several types of corrections. If, for example, a given thermistor changes temperature calibration as it moves vertically from one pressure range to another, the effects of this change upon the temperature would be reflected as a change in depth of isotherms upon the contour chart and would be removed when the true depth was read from this chart. The thermistor calibration problem then is one only for the stop position.

Data for the depth determination chart, (Figure 6) may be obtained in other ways. One is by obtaining simultaneous observations with the deep bathythermograph and the thermal-tow while the ship is underway. This method eliminates the necessity for assuming that the depths of isotherms remain constant for any significant period of time or over any significant area. However, it introduces difficulties such as the difficulty of lowering another cable while the thermal-tow is down and the ship is underway. This can be done but requires great care and some luck. On cruise 64-A-7 bathythermograph observations were taken every two hours without incident. The lowerings were only to depths of approximately 140 meters but they were of value in preparing the upper portion of Figure 6.

Another method consists of lowering the thermal-tow while the ship is drifting and taking a hydrographic cast while the thermal-tow is operating. The ship is then gotten underway at its cruising speed, raising the thermal-tow chain to its operating depth. After a suitable time, say 10 to 15 minutes, the engines are stopped and a second hydrographic cast is taken while the thermal-tow is operating (ship drifting). Interpolation between the two casts provides temperatures and depths for comparison to thermal-tow contour chart readings obtained between the two casts while the ship was underway.

USE OF THE DEPTH DETERMINATION CHART

For practical use, a reproduction of Figure 6 is made on transparent paper with the full vertical scale being 14 inches, thus matching the full vertical scale on the contour chart. To read isotherm depth from the contour chart at a particular time, the recorded chain-end depth for that time is noted. Then the ordinate of Figure 6 bearing this label is superimposed upon the contour chart at the time the readings are desired. The position where each isotherm crosses the ordinate is then noted and the true depth of the isotherm may be read off. It is the value of the sloping line which crosses the ordinate at that position.

OTHER SEA TEMPERATURE DATA FROM THE THERMAL-TOW AND ASSOCIATED DEPTHS

Available sea temperature data from the thermal-tow other than those indicated on the contour chart are the readings from the individual thermistors included in the typed print-out and on the punched tape. The only depth information associated with these temperatures is the chain-end pressure and the position of each thermistor along the 267 meter chain. The depth of a particular thermistor can be obtained from Figure 6. This would be done by selecting the vertical line representing the particular chain-end depth under consideration. At the intersection of this line and the horizontal line passing through the chain length at which the thermistor is found on the right hand ordinate or depth scale, the true depth of the thermistor would be read from the sloping or true depth lines. To expedite this procedure, since the thermistors are at fixed positions along the chain, horizontal lines might be drawn upon Figure 6 - one for each thermistor. These could then be labeled with the proper thermistor code number. Then for any given chain position the true depths could be read off where these lines representing the thermistor positions along the chain intersect the proper vertical lines.

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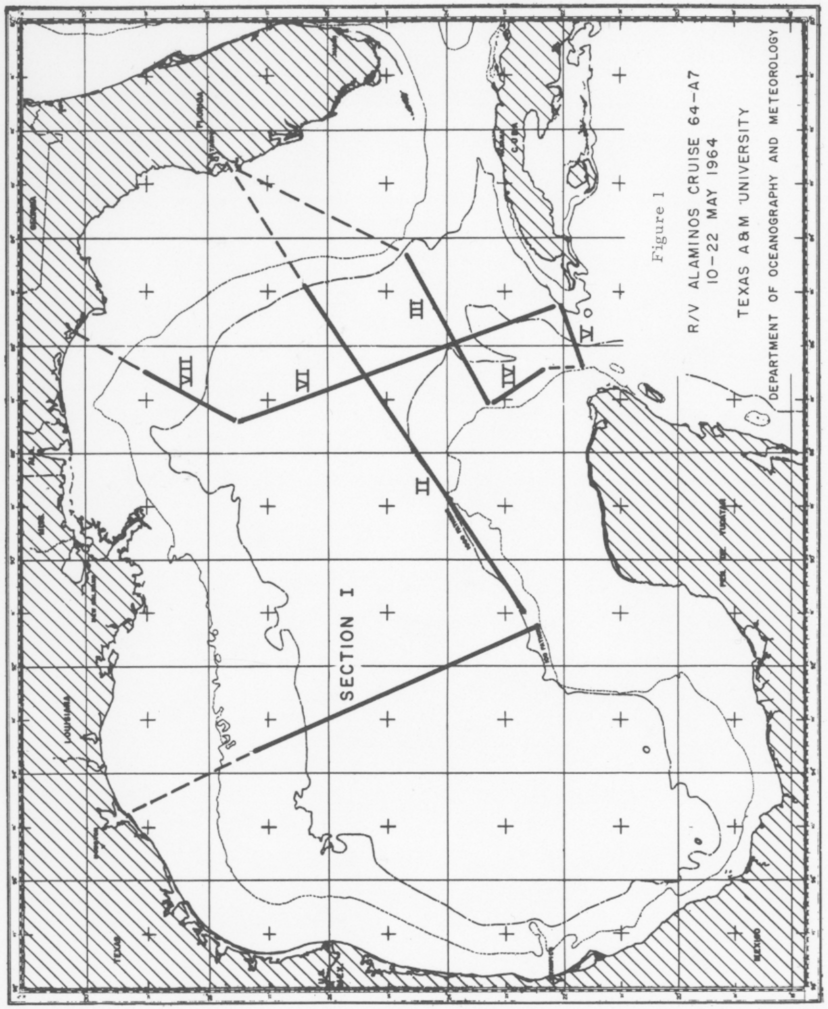
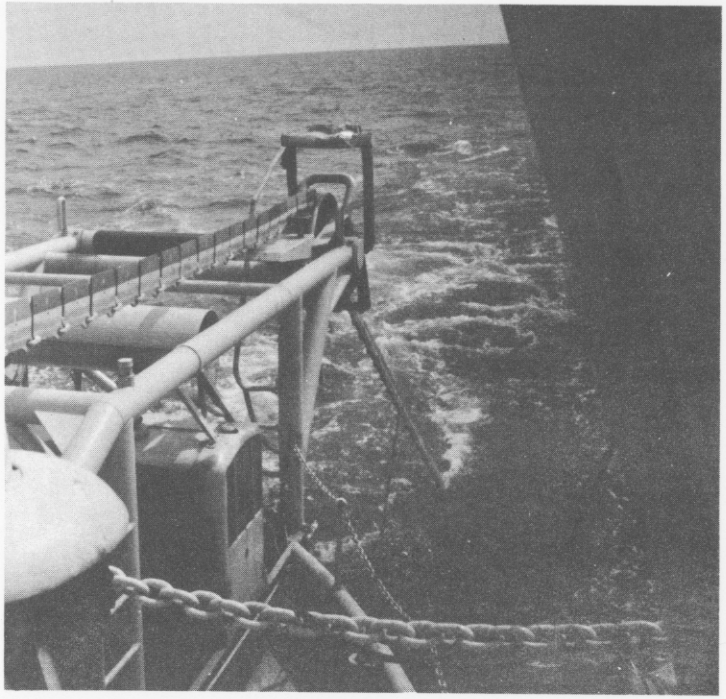


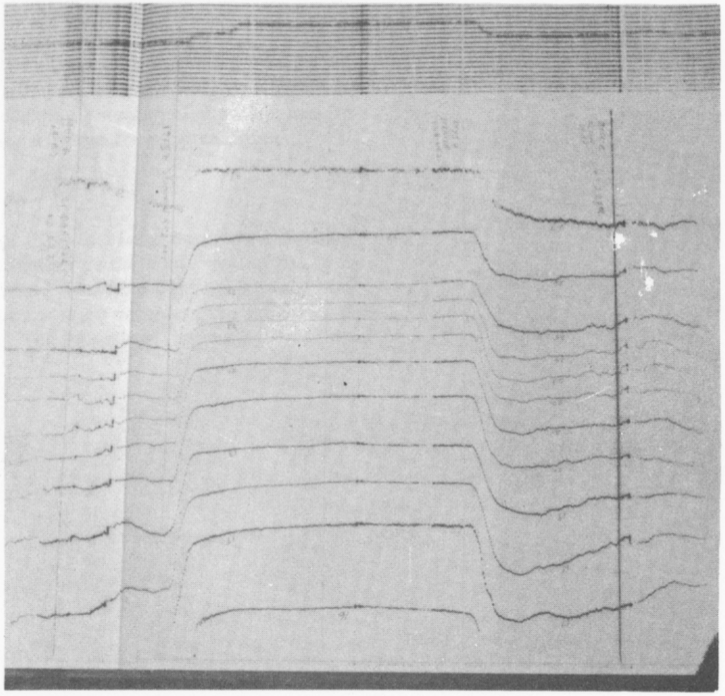
Figure 1

R/V ALAMINOS CRUISE 64-A7
10-22 MAY 1964
TEXAS A&M UNIVERSITY
DEPARTMENT OF OCEANOGRAPHY AND METEOROLOGY



Thermal Tow of the ALAMINOS at Towing Speed

Figure 2



Contour Chart for the Thermal Tow
Showing from Left to Right the Depth of Isotherms
with Ship Successively Underway.
Drifting and again Underway.

Figure 3

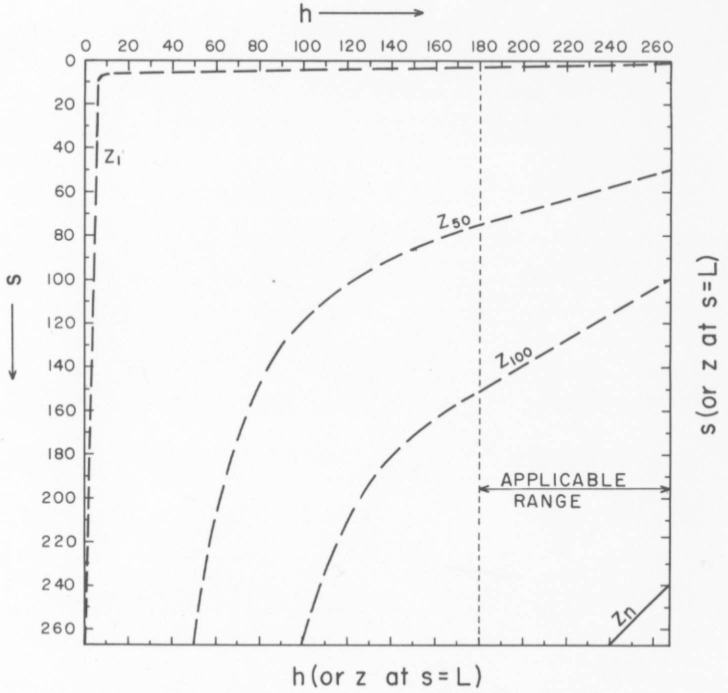


FIG. 4 CHARACTERISTICS OF LINES OF CONSTANT Z
L - TOTAL LENGTH OF CABLE SUBMERGED
h - DEPTH OF CHAIN END
Z - DEPTH BELOW THE SURFACE AT WHICH TEMPERATURE IS MEASURED OR INTERPOLATED
S - CABLE LENGTH BELOW THE SURFACE REQUIRED TO REACH THE DEPTH Z

TRUE DEPTH OF TEMPERATURE READINGS (267 M CHAIN)

(EMPIRICAL DATA)

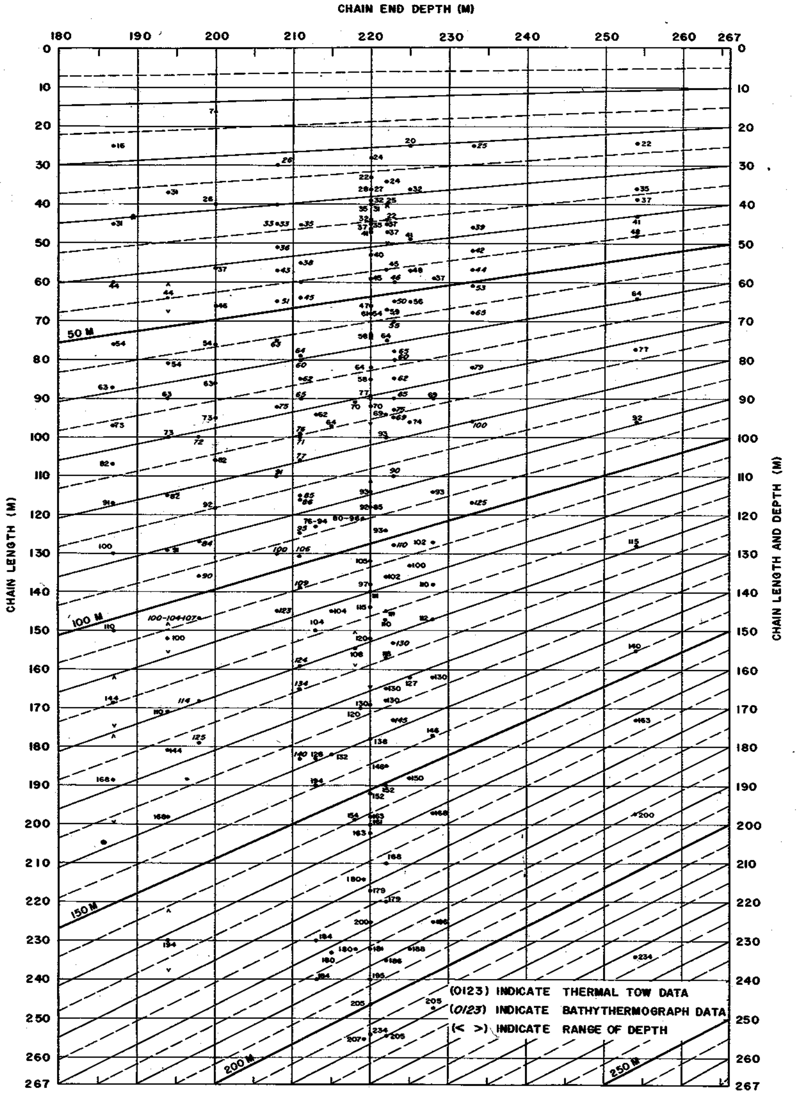
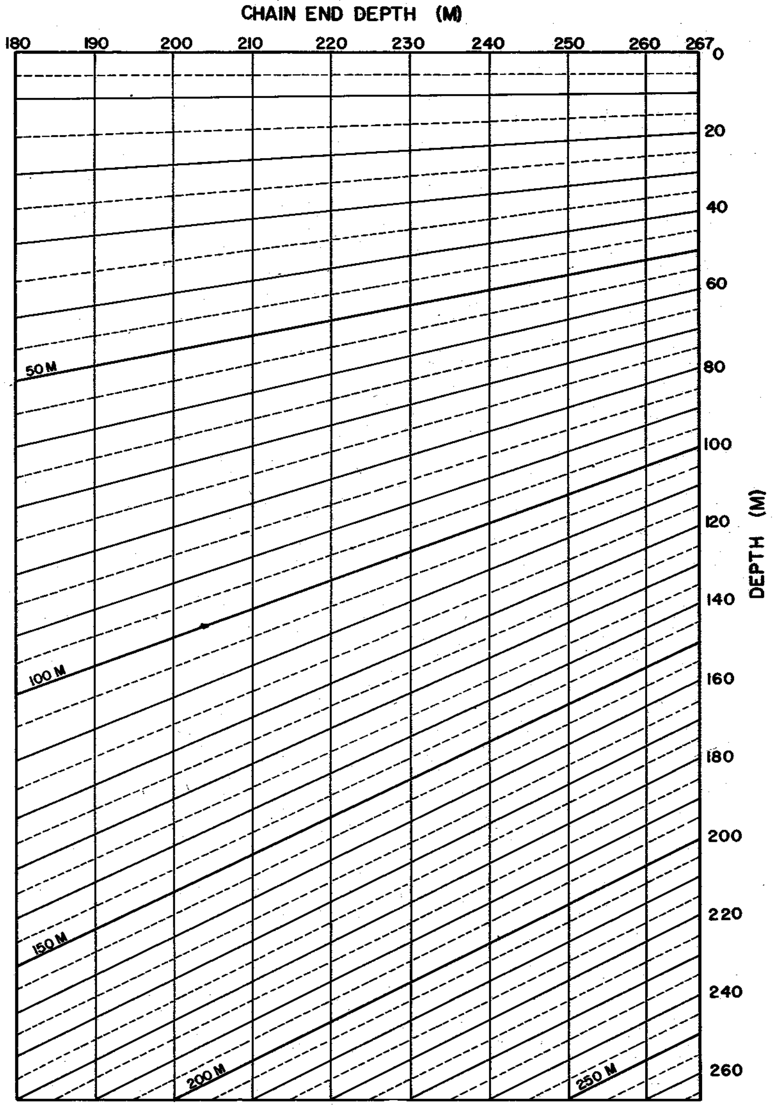


Figure 5

TRUE DEPTHS OF TEMPERATURE READINGS (267 M CHAIN)



CHAIN END DEPTH: TRUE DEPTH OF THE END OF THE 267 METER CHAIN, e.g. AS INDICATED BY THE PRESSURE ELEMENT ATTACHED AT THE CHAIN END.

Figure 6