The Isotherm Follower[1]

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ABSTRACT

The *isotherm follower* is an instrument that is capable of seeking out a given isotherm in the sea, locking on to the isotherm, following it up and down, and recording its depth with respect to time. This instrument has been employed singly and in triangular arrangements of three to provide the speed and direction of internal waves. It has proven to be valuable in determining the nature of vertical oscillations of sea temperature.

The principal oceanographic influence on the transmission of sound in the sea is the temperature structure of water. However, one bathythermograph lowering at a given time and location may not be representative of the vertical thermal structure in an ocean area for any length of time. This is because isotherms fluctuate vertically with reference to both time and distance. It is therefore evident that knowledge of the magnitude and geographic distribution of temperature fluctuations will help solve problems of sound transmission variations. To acquire such information, an oceanographic instrument called the *isotherm follower* has been developed at the U.S. Navy Electronics Laboratory.

This instrument is employed to seek out a given temperature, or isotherm, in the sea and to record its depth with reference to time. The follower plots vertical oscillations, or internal waves, as they pass the measurement site.

Description

The complete assembly (Fig. 1) comprises four parts: (1) a sea sensing unit; (2) an electric winch (containing a cable to which the sea sensing unit is attached); (3) an electronic unit (containing power-supply, servo-amplifiers, servo-mechanisms, etc.); and (4) two recorders (depth and temperature).

1 Grateful acknowledgments are extended to Mr. D. Baldwin for the electronic design, to Mr. J. Prince for its assembly, and to Mr. A. Arnold for the mechanical design. Mr. R. Rayment was responsible for some evaluation tests.

Sea Sensing Unit. This, the submersible section (Fig. 1 A), contains a temperature sensor (thermistor bead), which records the temperature at a particular location and depth on a panel-mounted meter. A second thermistor bead, similarly located and forming one arm of a bridge circuit, is balanced in another arm by a resistance corresponding to the desired isotherm temperature. If the bridge becomes unbalanced, a thyratron tube is fired. This activates a winch and causes it to raise or lower the sea unit.

This unit is a long, tubular section weighing about 30 pounds. The lower end contains the thermistor beads potted in "Scotch Cast" plastic; the upper end, and the electric cable, are fitted into the streamlined main body, which is about 4 inches in diameter. The main body is sealed from water pressure by means of O-rings and packing glands at each end. Inside its housing is a diaphragm-actuated pressure potentiometer. A second protective external diaphragm, separated from the first by an oil-filled area, has its surface exposed to the water.

The thermistor beads are set approximately 23 inches below the diaphragm that actuates the pressure-depth sensing unit. This gives a pressure differential of about 1 lb/in^2, for which correction has been made in the conversion of pressure to depth on the read-out of the recorder. The beads are set at a distance from the pressure element to avoid measuring the temperature in water turbulence caused by vertical movement of the main body; they are also mounted on a 2.5-inch elbow-like fitting to prevent sensing the temperature in the vertical path of the pressure element and cable.

The cable that leads out of the main body to the winch is Type MCOS-6 (six-conductor), and it is reeled over a sheave fitted with sealed ball bearings. The sheave is so balanced as to reduce friction on the cable to a minimum. The cable then feeds into the winch reel.

Winch. The winch and cable (Fig. 1 B) are readily portable and weigh about 130 pounds. The bitter end of the 230 feet of cable is fed into a hermetically sealed slip ring on the end of the winch. In the internal section of the shaft, a double packing gland acts as a water seal and a holding device for the cable. Holding is further guaranteed by the automatic switch on the winch, which leaves one lay of cable on the drum before the current is reversed. This prevents the reel from paying out too much cable on the winch, and it keeps the sea unit from being drawn up to the sheave and damaged.

The entire winch is mounted on a flat, reinforced metal base fitted with carrying handles. On shipboard, it is bolted to a platform clamped to the side of the ship; on the NEL oceanographic tower it is bolted to the deck grating.

The motor has a watertight cover which is splash- and drip-proof. A second electric cable, 25 feet in length, connects a junction box on the motor drive of the winch to the electronic equipment that feeds power to the motor of the winch reel. The $^1/_4$-hp motor, connected with an anti-back-drive gear box,

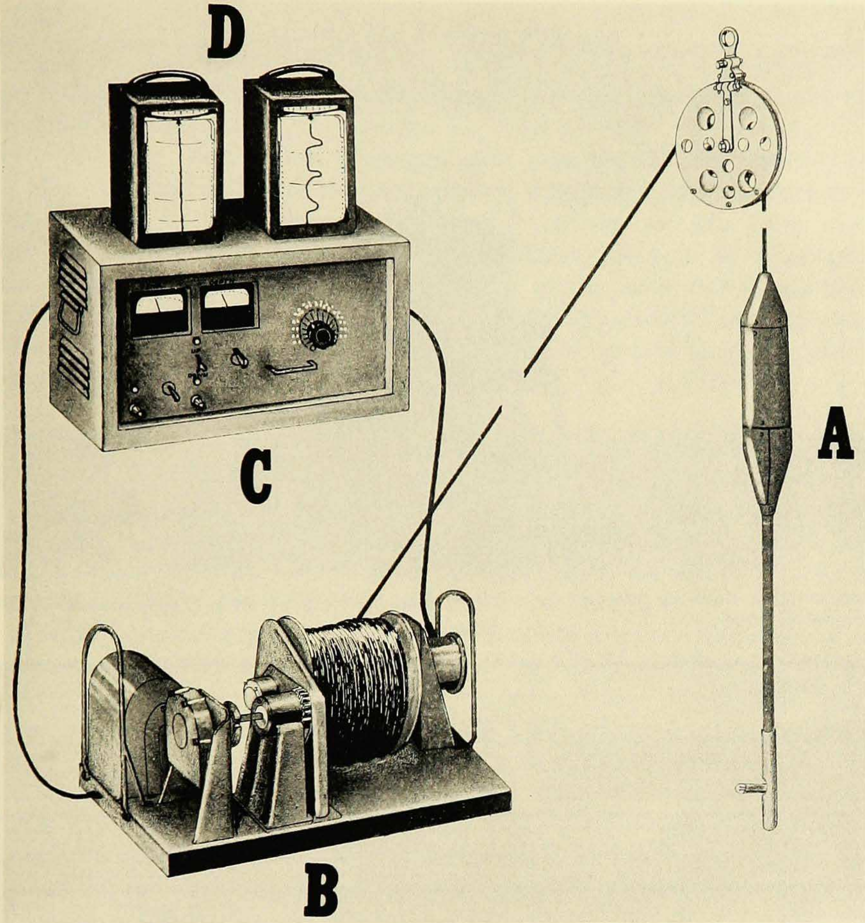

Figure 1. Isotherm Follower Assembly: *A*. sea sensing unit; *B*. electric winch; *C*. electronic unit; *D*. depth and temperature recorders.

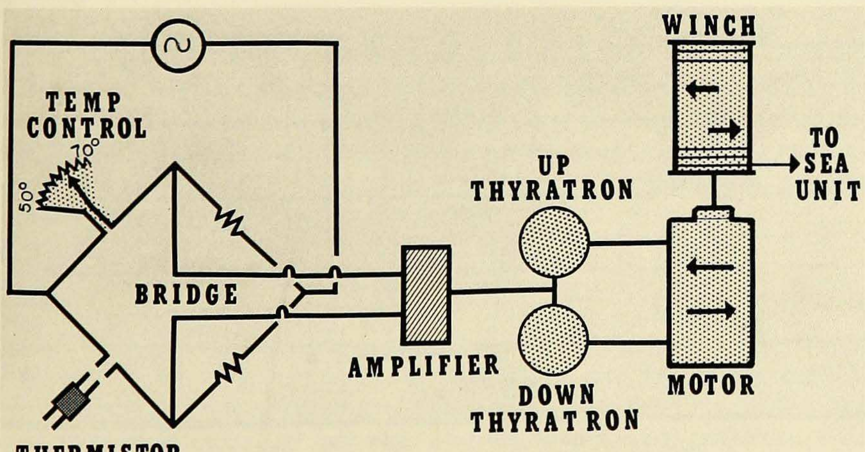

Figure 2. Schematic of electronic circuit of isotherm follower.

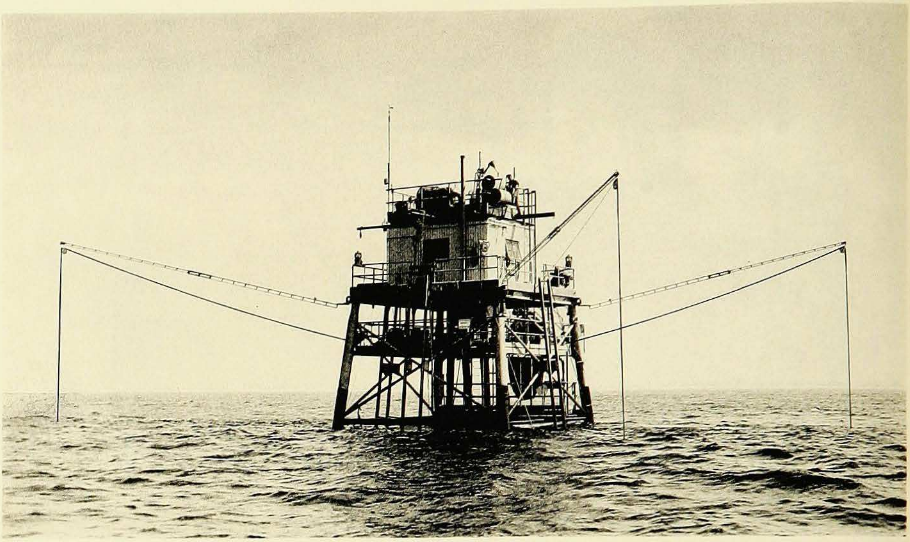

Figure 3. Three isotherm followers in operation from booms suspended out from the USNEL oceanographic tower.

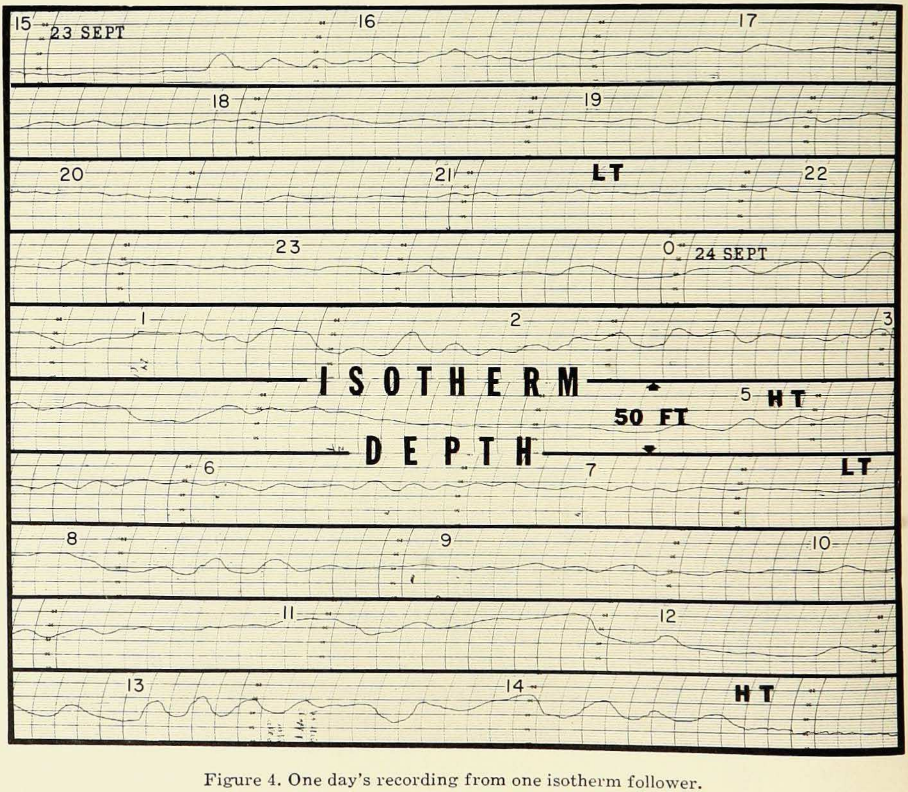

Figure 4. One day's recording from one isotherm follower.

runs both forward and backward, depending on the electric signal caused by changes in temperature.

A third cable, also 25 feet in length, leads from the slip-ring assembly to the electronic unit and feeds through a heavy, watertight coupling connector. The slip rings are of rodium-plated silver alloy and the two wire brush contacts are of gold alloy wire. It is sealed against moisture by a packing gland and O-ring seal placed at the junction of the male and female connectors. This signal cable leads from the slip-ring assembly into the electronic unit. Thus the electronic equipment can be remote from the winch assembly.

Electronic Unit. A third element is the packaged electronic unit (Fig. 1 C). Located on the face of its case is a master switch, which activates both the electronic system and the winch; a meter to indicate temperature; another meter to show pressure (or depth) of the sea sensing unit; and a dial that enables an operator to set, by resistance, the temperature desired, in 1°F increments between 50 and 70°F.

Two separate circuits are incorporated in the electronic unit: the temperature indicator consists of a thermistor bridge circuit, DC amplifier, and metering circuitry; the temperature-sensing thermistor bridge provides the error signal information to the servo-amplifier. Two thyratron tubes form the essential components of the servo-amplifier and allow current to pass to the winch motor (Fig. 2). The electric current from one tube (up-thyratron) causes the winch to run forward; the current from the other (down-thyratron) causes the winch to run backward. The winch will wind in or let out the sensing unit, depending on the signal it receives from the thermistor bead.

The pressure element, also a part of another bridge circuit, is connected to the calibrated depth meter on the case. This, like the temperature part, has a take-off to a recorder.

Recorders. One Esterline-Angus unit records the temperature (from 50–70°F) of the bead in the sensing unit, and another gives the depth. The latter can be operated at a full scale of 0–100 feet or, by interchanging the pressure transducer, to a full scale of 200 feet. Paper speed is adjustable, though it is normally set at one foot per hour.

Function

Tests. The thermal response characteristics of the isotherm follower were determined in the laboratory by means of a tube (8 feet long and 9 inches in diameter) containing a window 4 feet long. The tube was filled with almost equal volumes of water and kerosene. The desirable thermal properties of the two liquids, as well as their immiscibility, rendered a sharp temperature gradient between the two phases.

The sea sensing unit was lowered into the tube to the boundary region of the two liquids. At this juncture, thermal response tests were begun by setting the temperature selector at successive temperatures intermediate between that at the bottom of the kerosene layer and that at the top of the water layer. This condition caused the unit to respond in an oscillatory or hunting manner. It was found that, for a temperature gradient of 0.27°F/inch, the mean velocity was 3.7 in./sec. When the temperature gradient was reduced to 0.17°F/inch, the mean velocity of the follower was 1.5 in./sec. The frequency of the oscillations was found to be 66 cycles/min. The temperature differences at the interface caused the follower to overshoot the temperature it was seeking by the following amounts: at 1°F, 4.5″; at 2.5°F, 7.5″; at 3.2°F, 8.7″. The latter gradients are stronger than those observed in the sea.

The most complete tests were made during several sea operations. Since the temperature recorder provides a monitor of sensing unit temperature, it is run concurrently with the depth or pressure recorder. It was established that under the most adverse conditions the temperature remained within ±0.5°F of the temperature set on the control dial. This clearly demonstrated that the sensing unit was following the vertical oscillations of an isotherm in the sea.

Operation. To determine the vertical variation in any selected isotherm in the sea, the isotherm follower may be operated in one of several ways. It may be suspended from an anchored or drifting ship, with the sensing unit set at a given temperature, normally chosen from the sharpest part of the thermocline. Another *modus operandi* is from a moving vessel, wherein the follower may be towed at slow speeds to obtain the geographic distribution of the desired isotherm. At other times, two or more followers may be set at different temperatures in the same location to obtain vertical gradients.

For some studies it is desirable to record the temperature at the same depth in three locations. This can be accomplished conveniently by using manual control, adjusting the sensing unit to the desired depth, and allowing the temperature to record with reference to time. Such an arrangement has been operated continuously for seven days.

Another method, probably the most informative, deploys three sensing units in a triangular arrangement. When the time is synchronized, the direction from which the internal waves are coming is easily computed from the differences in time of arrival of the same wave at the three locations. One such operation was carried on from three fixed points of a triangle: (1) the NEL oceanographic tower, (2) an anchored ship, and (3) a small anchored float, each being located about 250 feet apart. The most convenient placement, however, was a triangular distribution of three followers suspended from

38-foot booms mounted on the NEL oceanographic tower (Fig. 3), with the three recorders located in the instrument house. Time markers in minute intervals were made simultaneously on the margin of the three tapes by means of a timing device. Under this arrangement, three units were operated continously for periods of up to seven days. One day's record from one isotherm follower is reproduced in Fig. 4.

Results

The nature of the observed internal waves, at the usual measurement site over the continental shelf near San Diego, Calif., varied from wave to wave. They frequently came in groups, separated by periods when the thermocline was relatively stable. However, at the measurement site, significant internal waves (*i. e.*, >2 feet in height and >2 minutes in period) were present 76% of the time, and the median of the significant waves had a height of 5.1 feet and a period of 7.2 minutes. Waves of this type are easily followed and graphically recorded with the isotherm follower.

Processing of such waves was accomplished by scaling off the depth of the isotherm for every minute and punching the values on IBM cards. Since the punching can be accomplished faster than the recording, backlogs of this phase of the processing were negligible. An analysis by computing machines will depend on the use to be made of the data. At the present time, depth-time gradients, wave periods, wave amplitudes, autocorrelations, and power spectrums with reference to time are being studied.

Thus the isotherm follower, which furnishes a record of isotherm depth with reference to time, has proven to be a useful oceanographic instrument for the study of internal waves.