遠洋水研報　第33号　平成8年3月
Bull. Nat. Res. Inst. Far Seas Fish., No. 33, March 1996

A Micro Bathythermograph System for Tuna Longline Boats in View of Large Scale Ocean Observing System

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Abstract

We designed a micro BT system for longliners operating in the tropics so that the basin scale upper ocean thermal field could be mapped efficiently. We discussed the size, accuracy, measurement range, and sampling rate of a prototype model of the micro BT system. For frequent use in actual fishing operation, recharging of the power and data transmission are performed through electro-magnetic coupling coils without cable connection. The system was tested repeatedly by attaching the probe to a longline during fishing operations in the central tropical Pacific. The prototype showed that it is not only able to measure vertical temperature profiles, but also to supply important information for fishing operations, i.e., deployed hook depth, and the behavior of hooked fish.

1. Introduction

Basin scale mapping of upper layer thermal field of the ocean is essential to detect the important signal of global scale interannual ocean-atmosphere variability, i.e. ENSO (El Nino Southern Oscillation). Upper layer thermal structure is necessary to understand mixed-layer dynamics, and also supplies useful information for fisheries. Subsurface temperature has been measured mostly by VOS (Voluntary Observing Ship) using XBTs. Cargo ships and tankers have been participating in the VOS. However, the routes of these merchant ships are mostly fixed. Therefore, the areas apart from these routes tend to be sampled sparsely (Figure 1).

Commercial boats of distant water fisheries, especially tuna longliners (hereafter simply referred to as longliners), often operate in these data-sparse areas. Mizuno (1994) developed a compact BT system and constructed subsurface temperature observing network in the eastern tropical Pacific Ocean by using the Japanese longliners since 1990 (Figure 2). Nearly 100 temperature profiles have been collected monthly by that fleet. Eastern tropical pacific is one of the major tuna fishing ground by longliners, and the longliners are feasible to obtain frequent BT data in the area approximately 10°S-10°N, 155°W-85°W as shown in Figure 2. On the other hand, the necessary sampling density to detect ENSO signal in the upper layer thermal field mapping is 2 samplings in

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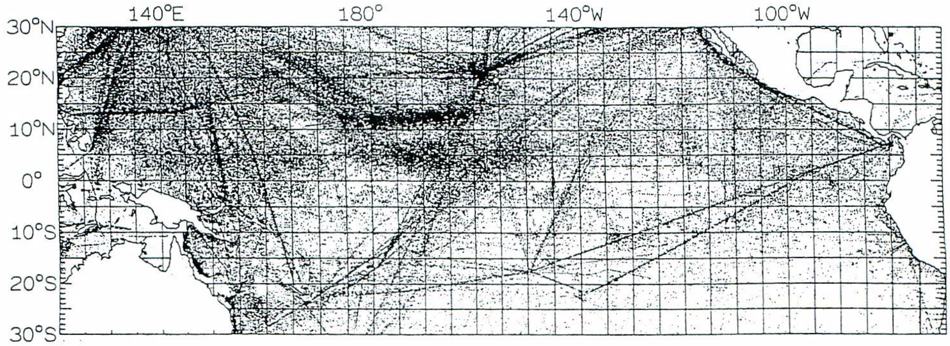

Fig.1 Geographical distribution of temperature/depth data in 1965-1986 (Mizuno and Yukinawa 1991).

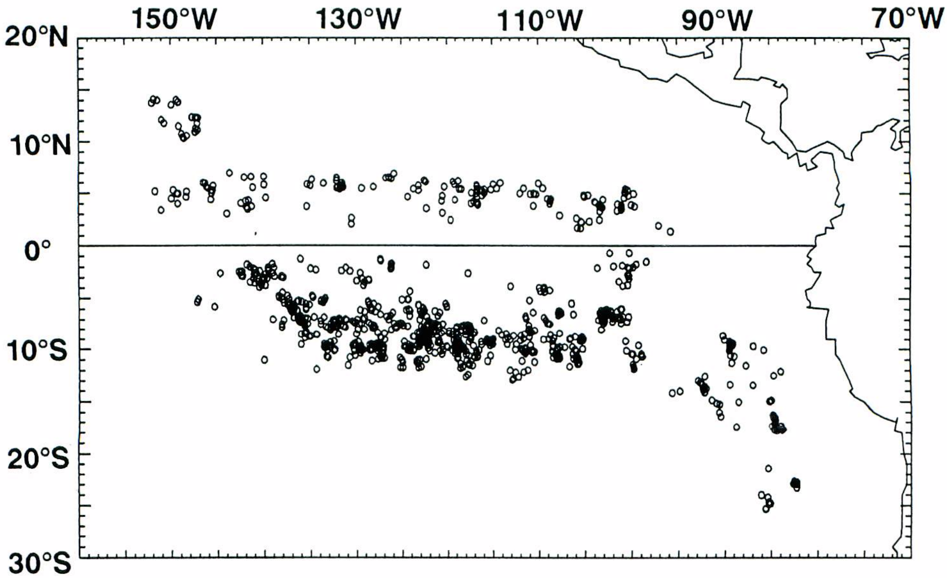

Fig.2 Distribution of temperature/depth data obtained by VOS longliners using compact BT in 1991 (Mizuno 1994).

a 1.5 x 7.5 degree latitude/longitude rectangle per month (Meyers et al. 1991). In the case of the observing area (10°S-10°N, 155°W-85°W), about 250 samples are needed for a month. Such criteria has not achieved in large part of this area, even adding international XBT observation. So, more data are required than we presently sample. However, it is not easy to increase the data number and extend the data coverage substantially to a satisfactory level. Because the BT observation is usually conducted separately from the fishing operation, fishermen have to spend considerable additional time and effort to collect BT data. An alternative approach would be to use XBT observation, but the XBT probes are expensive and the logistics are difficult, because the steaming routes and ports visited by the longliners depend primarily upon fishing conditions.

From the oceanographic point of view, fishing gears are ocean observation platforms. For

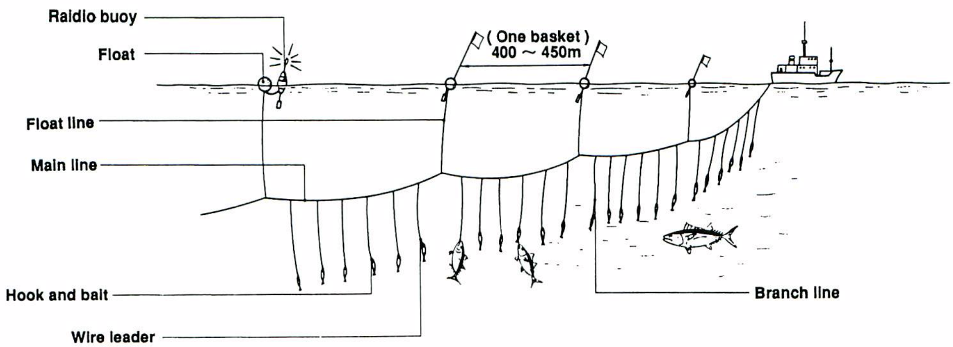

Fig.3 A sketch of longline operation (after Taiyo Gyogyo 1984).

example, a longline is a long rope with floats and branch lines, and the branch lines are lowered down to a few hundred meters (Figure 3). The segment of the main line between two floats is called "one basket". If oceanographic instruments are attached to such gears, they might supply useful oceanographic data.

Subsurface temperature profiles are necessary for fishing operations, especially for longliners in order to select the depths for hooks hanging from the main line. These depths should be set to coincide with a swimming depth of target species. The hook depth has been often estimated by assuming that the shape of mainline is a catenary curve on a vertical plane (e.g. Suzuki et al. 1977). The depth is controlled by changing the intervals between floats attached to the main line and thereby changing the degree of sagging. Since ocean currents are not uniform with depth, the vertical shear of the flow modifies the shape of the line away from theoretical catenary curve. Hanamoto(1987) summarized the various results of hook depths observed by depth recorders and showed that the real hook depths were shallower by 10-20% than calculated depths.

In order to measure the depth directly, depth recorder attached to branch lines have been used experimentally (Saito, 1973, Yukinawa and Miyabe 1984, Nishi 1990, Boggs 1992). Since these recorder are bulky, they are not suitable for practical use. It is preferable for the recorder to measure depth and temperature simultaneously. Recent progresses of electronics make it possible to manufacture temperature/depth sensor in much smaller size. Therefore, we tried to develop a new micro bathythermograph (micro BT) system suitable to longline operation.

There are several advantages for temperature/depth measurement by longline fleets: Their area of operation is global and not confined to merchant ship lanes. Therefore, the longline fleet can collect data from areas that would otherwise not be sampled. Secondly, the micro BT attached to the gear is able to monitor the depth of hooks, and such information makes the longline operation more efficient. Moreover, it supplies biological information of target species such as their swimming depth, hooking time and their behavior when they hooked.

Recently several types of depth or temperature recorders were developed. Most of them are archival tags with various sensors (e.g. Sato et al. 1994). These tags are attached to animals and record environmental parameters (e.g. pressure, temperature, light intensity, etc.), and the tag is retrieved with the records when the animal is recaptured. It is designed to obtain a long time series record (several weeks to a few years).

On the other hand, this micro BT was designed under a quite different concept from the archival tag. The probe is attached to fishing gear in each operation which lasts some 20 hours, and the data are inspected shortly after each operation to verify the hook depth and then used to modify the depth for the next operation. So, the BT should be designed to be relevant to frequent and short term (tens of hours) measurement.

In this paper, the design concept of the micro BT system is discussed, along with a description of the prototype model and the results of its use.

2. Concept of design

2. 1. Size and Weight

Since a line of longline is approximately 100km long, it is difficult to transmit data from the BT to the ship electrically or acoustically. Therefore, the BT must be self-contained type (i.e. internally recording). The size is a compromise between the demands of miniaturization and ease of manufacture. However, miniaturization without specific purpose is unwise, we should find the most appropriate size which can be handled without bothering the fishing operation. It turned out that a size similar to a bait is the most appropriate.

2. 2. Sampling interval

This system is designed to measure temperature (T) and depth (D) as a function of time. T/D profiles (i.e. vertical temperature profiles) are measured when the probe moves down or up with branch line during the course of setting and retrieving the main line.

The sampling interval has to be considered carefully because it influences the vertical resolution of T/D profile. This resolution depends upon the purpose of study. As previously mentioned, we require T/D data to study basin-wide oceanographic variabilities. In the tropical Pacific, Meyers (1991) showed that minimum requirement of vertical resolution is 5m for the thermal field mapping to detect basin scale variability. Knowing this, the appropriate sampling rate can be determined by obtaining the falling or rising rate of the gear. This can only be estimated empiri-

Table1. Sinking speed of long-line measured by depth meter

Ship	Date	Field	Material of main line	Sink. rate (m/sec)	Author	Remarks
Shoyo Maru	1983.11-12	Indian Ocean	Cremona (6.35mm ϕ)	<0.1	Yukinawa and Miyabe (1984)	
Kagoshima Maru	1987.5	Eastern Indian Ocean	Man-sen (6.35mm ϕ)	0.1-0.2	Nishi (1990)	calculated from T-D curve figure
Townsent Cromwell	1989, 1990	off Hawaii	Nylon monofilament (3.5mm ϕ)	0.1-0.2	Boggs (1992)	calculated from T-D curve figure
Kaihatsu Maru	1994	Eastern tropical Pacific	Man-sen (7.2mm ϕ)	0.1-0.3	JAMARC (1993)	calculated from T-D curve figure

cally by referring to previous in situ depth-meter records attached to longlines. Table 1 shows available results of the field experiments. The depth-meters used in these experiments were made to be neutrally-buoyant by attaching small float. The falling rate was about 0.1-0.2m/s., indicating that a sampling interval of 10 second is sufficient to obtain a vertical resolution of 5m.

One of the important purposes for this BT is to monitor the settled depth of a hook. It takes 10-20 hours for each operation (from setting to retrieving the mainline). The hook depth can fluctuate considerably with a depth range of 10-30m and periods of 15 minutes to 5 hours (Nishi 1990). This variability will be well documented at a sampling interval of 10 second.

Another purpose is to detect the behavior of tuna when hooked. A time-depth record will show when and at what depth a tuna was hooked and how the fish behaved. The behavior of hooked fish is not well known, since obtained records revealing the detailed behavior of hooked fish are few. Nishi (1990) described two cases in which a fish was hooked by a branch line neighboring to a depth recorder attached to branch line. It was detected that a tuna moves up and down abruptly for a while, but it gradually calms down. The record showed that the shortest period of depth change is a few minutes which can be described by 10 second sampling interval. Taking account of above requirements, we chose 10 second sampling interval.

2. 3. Precision and range of measurement

The maximum depth of measurement depends upon how deep the hook is set. The configuration of the gear is changed by target fish species and operation area. In the tropical area, deeplining which targets bigeye tuna has well been established. Deepline reaches deeper than 200m according to catenary curve assumption (Suzuki 1977). The length of mainline for a basket is 500-600m for deepline (Suzuki 1977). Since maximum depth must be less than half of the interval (i.e. 250-300m), a depth of 500m is assumed as a maximum measurable/endurable depth for the designing of the sensor.

The specification of measurement is shown in Table 2. Precision for temperature measurement is better than XBT (0.1-0.2°C ; Pazan and White 1989). Also the depth error is smaller than XBT. Since the probe is retrievable, the depth error can be calibrated by laboratory tank experiment afterward.

2. 4. Power supply

Ideally, the BT case should not be opened in order to avoid water leakage. If the case is sealed, battery charge and data transmission through connecting line are difficult. It is preferable to display obtained data immediately after an operation to verify the hook depth. In this case, long life battery is not necessary. Therefore, we do not use battery but instead a condenser, which is quickly rechargeable by electromagnetic coupling. It can be recharged from outside the case, and also memorized data can be transferred through the coupling.

2. 5. Data storage

One operation usually takes about 20 hours, and this results in 7200 T/D pairs of stored data at the 10 second sampling interval. If a pair of data (T/D) uses 4bytes, then the total data size is 28.8kbytes. Taking account of this memory requirement and economizing manufacturing cost, a 32kbytes flush memory is chosen for data storage.

3. Outline of the Model

A prototype model of the system consists of three major units, namely, probe, pod and controller units (Figure 4). The probe is attached to the fishing gear and launched to the sea and records temperature and depth data during operation. Housing of the probe is made from poly-carbonate. Temperature and depth sensors are installed at both ends of the unit. Table 2 shows the specification of the sensors.

The probe has an induction coil inside, and is put into a pod (Figure 4 ; lower panel) which has a coupling coil. The data signal generated by the coil in the probe induces the same signal in the outer induction coil installed in the pod. The signal is transmitted from the pod to a computer through a RS-232C interface.

Since the probe has no switch, initialization of the memory and start of measurement is controlled by the pod. Putting the probe into the pod prompts the transmission of the stored data to a computer and at the same time begins the charging process. The data received by the controller (i.e. computer) are in standard ASCII text format having sequential depth and temperature pairs with some header data (starting time, sampling interval, etc.).

After data transmission and charging, the probe is ready to be taken out of the pod. Taking the probe out of the pod clears its memory and prepares it for data sampling. It takes a few minutes to recharge the condenser and transmit the data from the probe to a computer.

Table2. Specification of micro-BT (Mark-1)

Dimension (Length × Diameter)	170 × 18 ϕmm
Weight	75g (37g) (in water)
Sampling Interval (Temp./Depth)	10sec.
Sensors	
Temperature (Platinum Resistant)	
Measurement Range	−2−32°C
Resolution	0.1°C
Precision	±0.1°C
Time Constant	800msec.
Depth (Strain gauge)	
Measurement Range	0−500m
Resolution	1m
Precision	±2m
Time Constant	200msec.
Data Storage	32kbyte

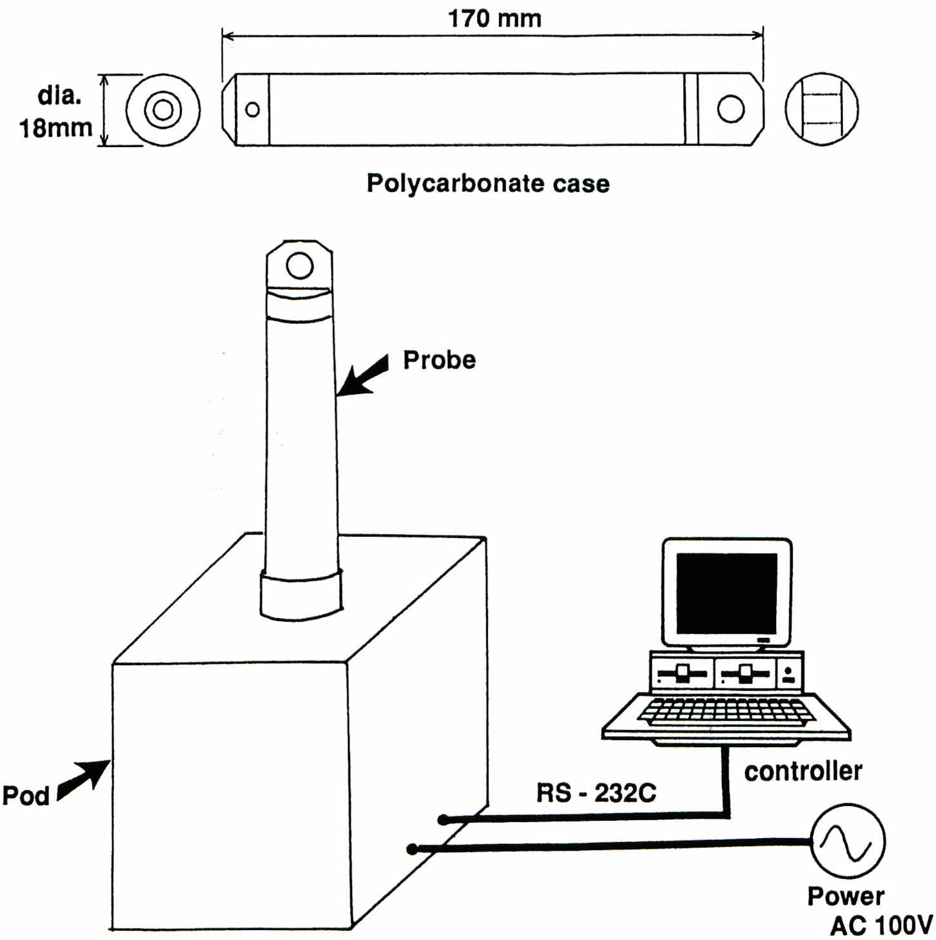

Fig.4 A sketch of the micro-BT system, probe (upper panel) and overview of the system (lower panel) when the probe is returned to the pod.

4. In-situ experiments

A fisheries training vessel Shin'kai Maru (Department of Education of Shimane Prefecture) conducted a cruise (Jan. 12-Mar.22, 1995). In this cruise, training longline operations for fisheries high school students were performed in the central tropical Pacific (10-20°N ; 180-160°W) where the North Equatorial Current flows (Figure 5).

Taking advantage of this opportunity, we made field experiments for the micro-BT system. In an operation, 190 baskets were used, and each basket includes 12 branch lines. The probe was attached to the sixth branch line in a basket (i.e. the deepest line). Since only one prototype model was available, it was used repeatedly during the cruise.

4. 1. Attachment of probe

In order to find the most appropriate part for attachment of the probe to the gear, three

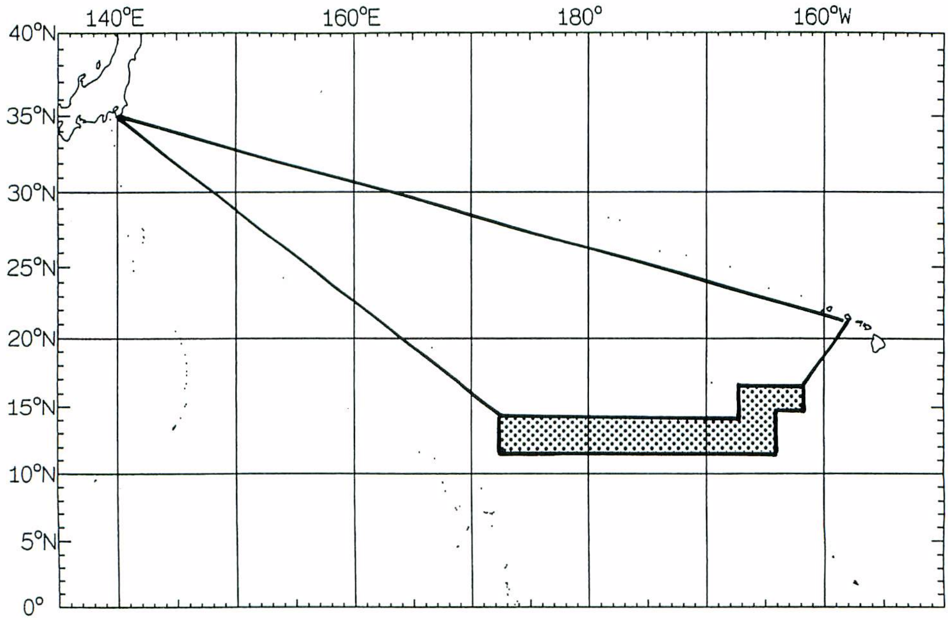

Fig.5 The field of in-situ experiment (dotted area) and cruise track of Shin'kai Maru, during Jan.31 to Mar.1, 1995.

different positions on a branch line (Figure 6) were tested. Position (1) is the upper end of a branch line, actually just below a snap. This position is appropriate to estimate the underwater depth of the main line. Position (2) is in the middle part of the branch line, and is the upper end of a steel wire. Position (3) is the end of a branch line replacing a hook. This position is the most preferable to measure the hook depth directly.

Measurements were repeated ten times at positions (1) and (3), and eight times for the position (2). It was found that position (1) is not appropriate, because it sometimes interfered the action of un-snapping a branch line when retrieving. The position (3) had a critical problem that no fish behavior data are available without a hook. The position (2) did not interfere smooth operation and is close enough to the hook to estimate its depth. It was concluded that the position (2) is practically the best of the three.

4. 2. Obtained Data

An example of obtained data is shown in Figure 7. The upper panel shows time-depth record with 10 second time interval. The record can be broken down into five periods (A-E). The period A indicates that the probe was still staying on deck before launch. The depth was stably near zero. The period B indicates that the probe was falling down into the sea. The gradient of the curve denotes the falling rate. The period C shows that the probe reached to a certain stable depth (about 205m) and the longline has been settled in the water. The record shows that the branch line was fluctuating vertically. This fluctuation is probably due to the shear flow. The period D indicates the retrieval of the longline (i.e. the main line was being hauled). And the period E indicates that

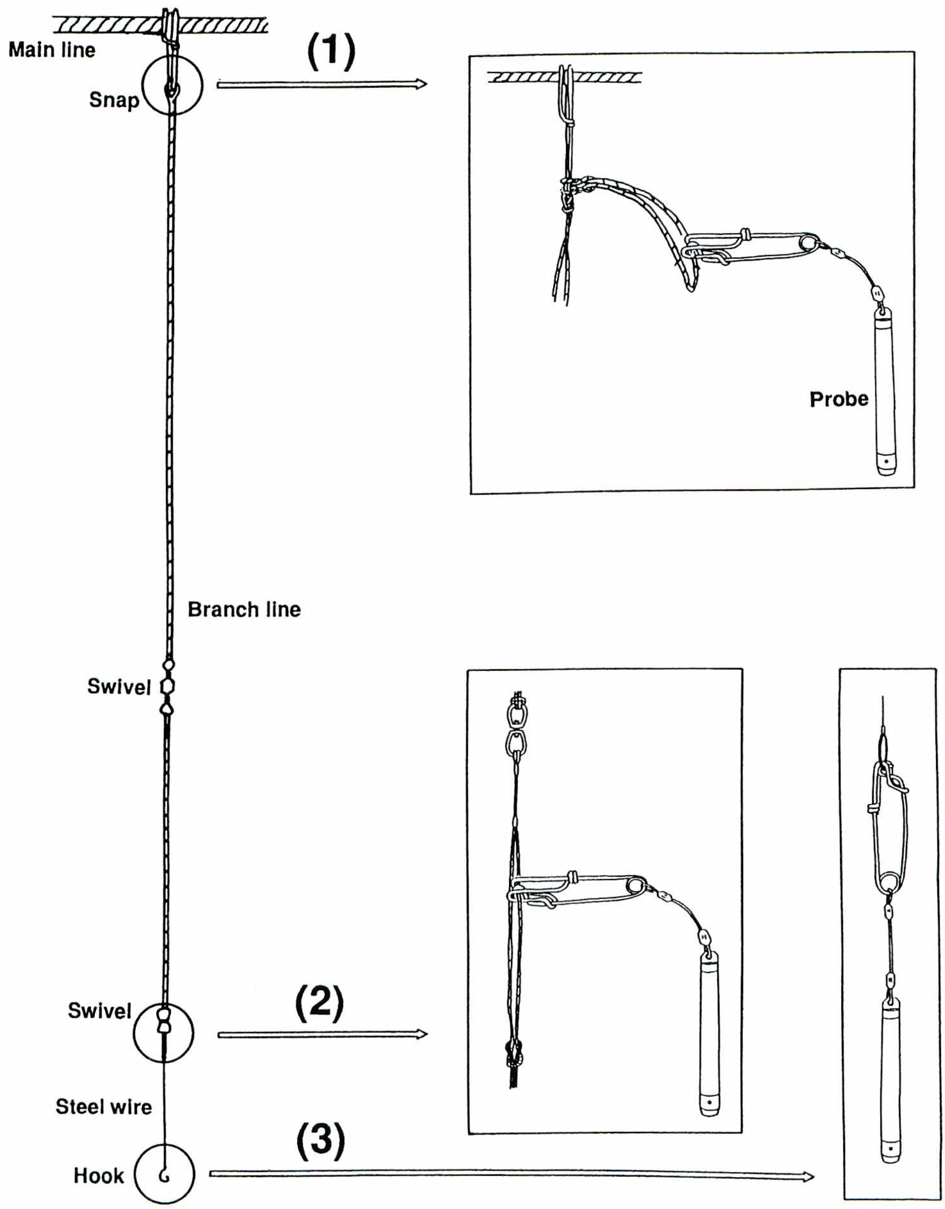

Fig.6 A sketch of a branch line with sensor. Three different attached positions (1-3) of the probe are shown.

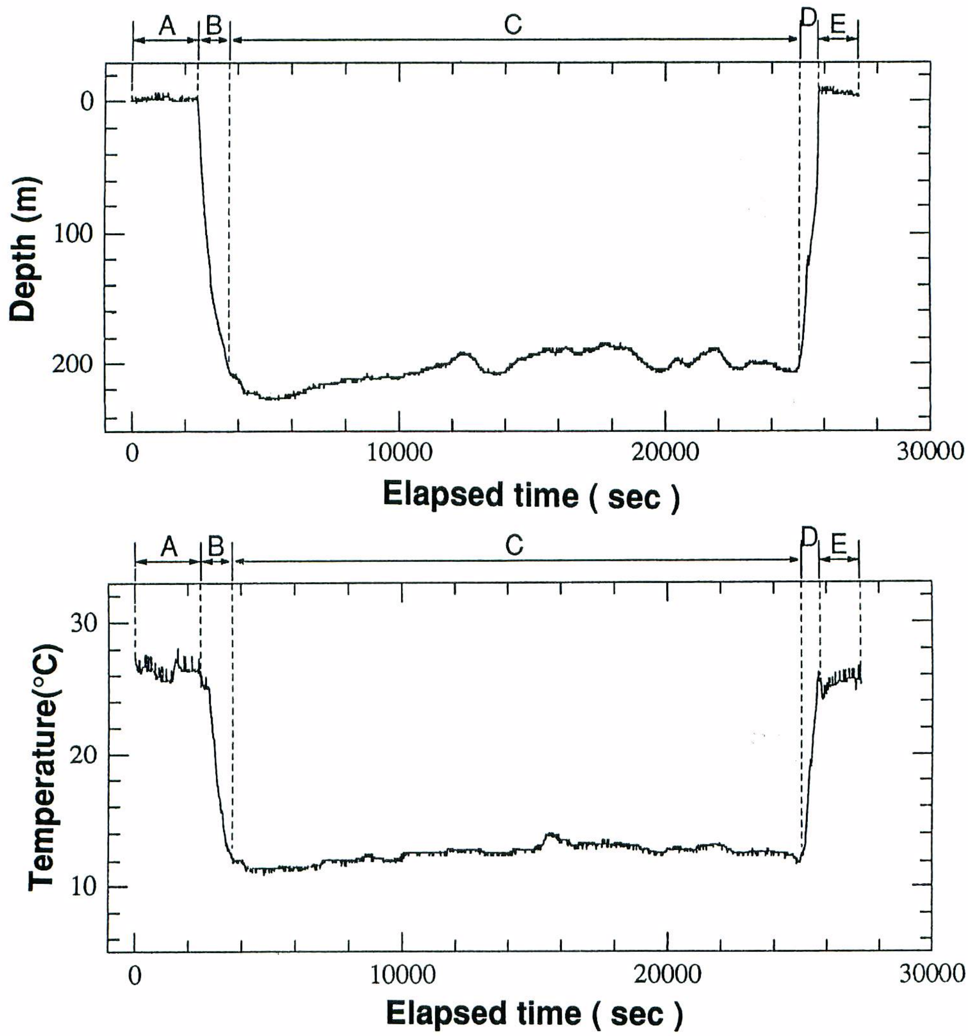

Fig.7 An example of obtained data (13° 05'N ; 174° 08'E, Jan. 29 1995). Time-depth profile (upper panel) and time-temperature profile (lower panel). Measuring period is divided into four periods (A-E), namely, the probe is staying on deck (A), falling with the branch line (B), settled at depths (C), being hauled to deck (D), and retrieved to deck(E).

the probe was retrieved to on deck.

4. 3. Vertical temperature profile

A vertical profile can be observed during the period of B and D in Figure 7. But falling period is preferable for the profile, because the depth change is slower and more uniform in falling period. The rising speed is not uniform due to changes of hauling rate of main line in response to unhooking fish or other deck work. The probe even moved down sometimes.

Since the probe starts to sample the data in air, the sea-surface must be detected from the

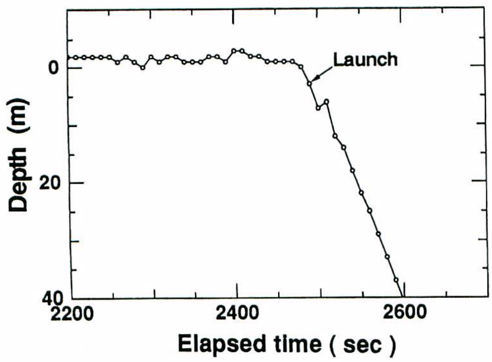

Fig.8 Detection of launching time in time-depth record shown in figure 7. The boundary of period A and B in Figure 7 upper panel are zoomed.

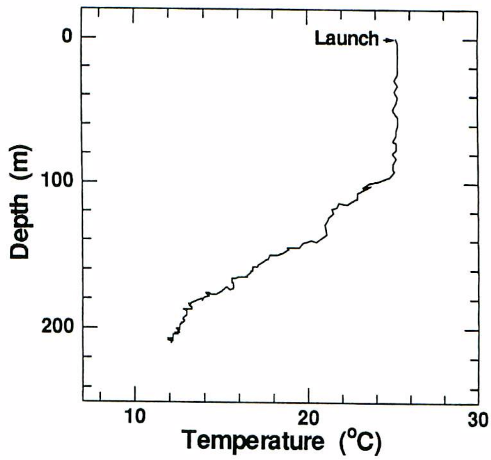

Fig.9 Vertical temperature profile from the data shown in figure 7. Only the data in period B (falling period) are used.

record. The surface is detectable by time-depth data. Figure 8 shows the time sequence of depth, actually it is an zoomed part of Figure 7 around the boundary of A and B. An abrupt depth change can be seen clearly.

An obtained vertical profile of temperature is shown in Figure 9. The profile was constructed by using the data before the branch line was settled (i.e. period B in Figure 7). The surface mixed layer (0-100m) and thermocline below can be clearly seen.

4. 4. Falling rate

By using the data of period B, the falling rate can be calculated (upper panel of Figure 10) to reach a maximum (0.5m/s) within 100 second after launch, and then it gradually slowed down and finally settled within 1200sec. or so. The averaged falling rate is 0.1-0.2m/s consistent with the previous studies.

An example of rising rate was also displayed (lower panel of Figure 10). The rising rate is larger than falling, sometimes exceeding 1m/s, and it fluctuated considerably. The rising starts about 400sec. and the rate increased gradually, but slows down at around 750sec. and then increased rapidly at about 1100sec. This fluctuation indicates that a line hauler operator controls the hauling speed of mainline so as to synchronize to the deck work. It is confirmed that the falling period is much preferable than rising period for measurement of vertical profile of temperature.

4. 5. Records at hooking

On 28 occasions, a bigeye tuna was hooked by a branch line with the probe. Unfortunately, the data were not recorded because of a malfunction of the system. However, we did record three cases in which a bigeye tuna was hooked by the branch line right next to the branch line with the probe.

One of these examples is shown in Figure 11. In this case the probe was attached to the

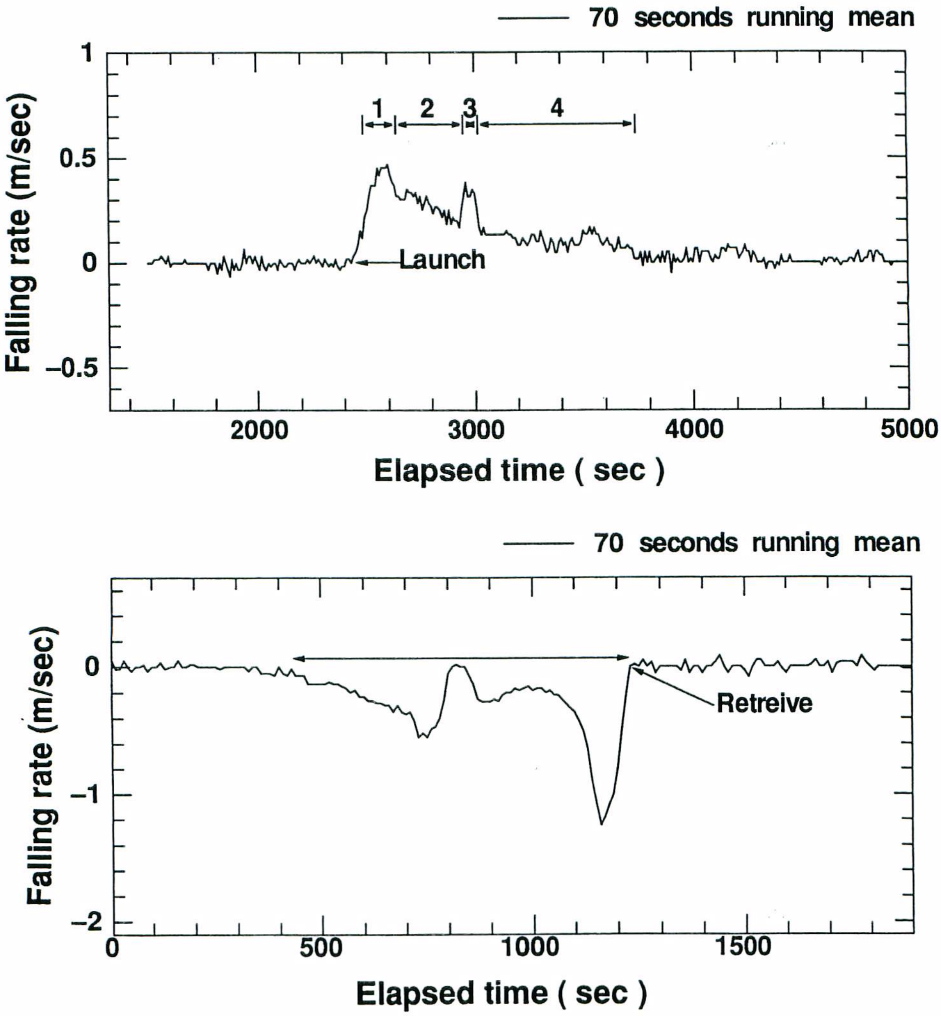

Fig.10 Upper panel ; Falling speed of the probe with time when the gear was set. The speed was calculated by using 7 data (70 sec.) running mean average. Positive (negative) values denote falling (rising) speed. Lower panel ; Same as the upper panel, but when the gear was retrieved.

position 2 shown in Figure 6. An abrupt depth change at shortly before 10,000sec. denotes the hooking. The fish raised the line by about 40m at least, and the line went up and down repeatedly corresponding to the behavior of the fish and then it gradually decreased. The movement continued by the end of the operation, indicating that the fish was captured alive. The weight of the fish (bigeye tuna) was 36 kg (121cm in fork length).

In all three cases, the hookings occurred after the branch lines reached stable depths, and three bigeye tunas were hauled to deck alive. The records showed the similar features, going up about 40m abruptly immediately after hooking and then became calm.

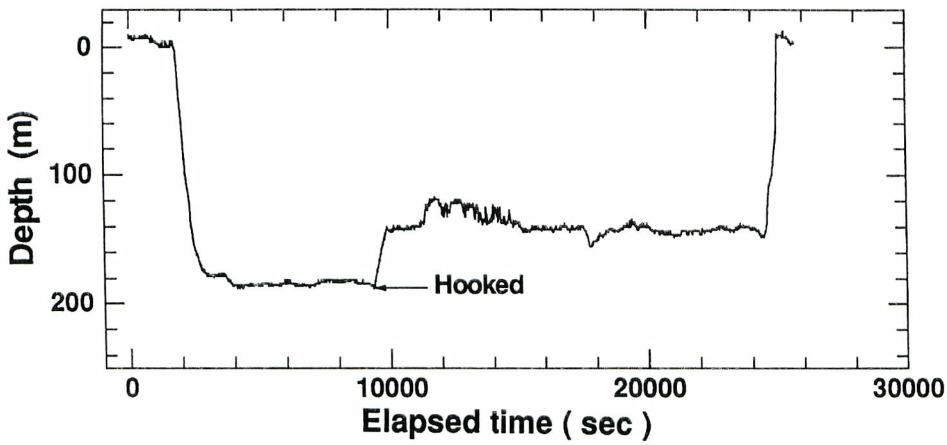

Fig.11 A time/depth record when a bigeye tuna was hooked.

5. Discussion

In the tropical area, the major target fish for longliners is bigeye tuna. According to recent field experiments, most of them are caught at depths of greater than 200m (Boggs 1992). The hooks are usually deployed so as to reach to deeper than 200m in operation. As shown in this experiment, the maximum depth of measurement with the micro BT attached to longline would be about 200-250m, which is much shallower than XBT measurement with T-4/6 types of probe (460m).

In the tropical area, 20°C isotherm is indicative of upper layer thickness, and it seldom reaches to 250m in the Pacific (Mizuno and Yukinawa 1991). So, the tropical longliners are feasible to supply useful data for upper layer thermal field (i.e. upper layer and surface mixed layer structure), if they widely use our probe.

Time and position data are critically important for T/D data. Time data is available from an IC clock installed in the probe. Position data are available from ship's navigation system (i.e. GPS ; Global Positioning System). Since we prefer down cast data for T/D profile, launched position is needed. In this experiment, position data was written down manually. In the next step, we are planning to detect launched position automatically. The controller of this micro BT system (i.e. a computer) is to receive position and clock data from GPS and memorize them for a certain period, say recent 24 hours or so. It also transfers newest clock data to the probe through the pod. By referring to the data, the probe is able to adjust its clock. The probe knows the time by its own clock after it is taken out of the pod. The launched time of the probe can be detected from time-depth record (Figure 7). The launched position can then be obtained by searching the time and corresponding position data in the GPS time/position table recorded in the controller after measurement. Also retrieved position and time can be obtained in a same way. The difference of the positions (launched and retrieved) indicate drift of the entire gear by ocean current. The major part of this drift may be explained by geostrophic current because of it's spatial scale.

In order to obtain launched and retrieved time and position automatically, sea-surface must be detected automatically. If the depth sensor is ideally precise, the surface data will be found easily by looking for the nearest positive depth to 0m. The depth data in air is to be zero, but depth sensors generally have unavoidable small bias and noise which can be seen in Figure 7 also. However, sea-surface is distinguishable by eye inspection of time depth record. Such detection must be performed by computer for automatic detection.

A time-depth record showed that real hook depth is shallower than the estimated depth by catenary curve assumption by 0-23%, indicating that the line was lifted up by shear flow. A shape of longline can be estimated much better by attaching the probe to each branch line in a basket.

Recently, Boggs(1992) used hook timers and TDRs (time depth recorder) attached to longline, and found that significant proportion of the captured fish were hooked during falling and rising of the gear. If a number of probes are attached to the branch lines, information on hooking time and depth and fish behavior might be increased drastically. For further development of the system, it is desired to make the cost of the probe less, and multi probe processing for the controller is important.

6. Summary

We designed a new model of micro BT system relevant to tuna longliners, and made a field experiment in the central tropical Pacific. The results obtained from the experiment are as follows;

1) The probe detected the vertical profiles of temperature, the hook depth and the behavior of hooked tuna with a sampling interval of 10 seconds.
2) The most appropriate position for attaching this probe is the upper end part of steel wire of a branch line.
3) Vertical temperature profiles obtained in falling period (i.e. from launch to settling to depths) of the probe is preferable to that in rising period.
4) A function of receiving position data from GPS system is recommended.
5) If this model is used by commercial longliners, they will supply considerable amount of T/D data useful to basin-wide mapping of upper layer thermal structure.
6) In return, the commercial longliners will learn more about the behavior of their gear and of fish.

7. Acknowledgment

We acknowledge the captain Shigeo Takao and his crew of Shin'kai Maru for their cooperation with the in-situ experiments, and Mr. Kiyoshi Katsuyama of Fisheries Agency for helping us to coordinate this experiment. We apprcciate Dr. George Cresswell for his kindness in correcting the manuscript. This study was supported financially by the Agriculture, Forestry and Fisheries Research Council of Japanese Ministry of Agriculture, Forestry and Fisheries under the coopera-

tive study of national/private institutions.

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大規模海洋観測網に寄与するまぐろはえなわ用
小型水深水温計システムの開発

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