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Instruments and methods

Start-up transient of XBT measurement

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Abstract

The start-up transient of XBT measurements is statistically investigated for five types of recorder system: Z-60-16 II and III by Murayama Electric Co., Ltd., and MK-130 by Tsurumi Seiki Co., Ltd., which are commonly used in Japan, and Sippican MK-9 and MK-12, which are popular in the United States and other countries. The UNESCO recommendation to exclude XBT-measured temperatures in the top 3.7 m layer from the bathythermograph report is justified within a nominal precision of 0.2°C for Tsurumi Seiki T-7 probes. However, it is shown that the depth where the transient ceases differs for different types of recorder. If we require a more strict accuracy constraint of 0.02°C, the estimated depth of the transient is 2 m for MK-130, MK-9 and MK-12, 3 m for Z-60-16 III and 10 m for Z-60-16 II.

Keywords: XBT; Expendable bathythermograph; Start-up transient; Sea surface temperature; Temperature measurement; Temperature data; VOS monitoring

1. Introduction

Expendable bathythermographs (XBTs) have been widely used since the early 1970s for measuring temperatures of the upper ocean. Observations of sea surface temperature (SST) are desired from these abundant XBT measurements. However, since it takes a finite time for an XBT probe to adjust to the temperature of the surrounding water after entering the sea, data obtained by XBTs near the surface should be treated with caution.

Bailey et al. (1989) estimated the depth of this initial temperature transient, often called the "start-up transient", to be 3.7 m by comparisons with colocated CTD measurements. Based on their estimate, UNESCO (1997) recommended that temperatures measured in the top 3.7 m layer of the ocean should not be included in the bathythermograph report of XBT measurements. Roemmich and Cornuelle (1987) tested 96 XBT probes in a precision temperature bath and identified two types of transients: a shorter one due to the electronic transient and a longer one due to the thermal mass of the XBT nose. However, they only examined "Deep Blue" probes and MK-9 recorders by Sippican Inc. It is unknown if the depth of the start-up transient is the same for other types of recorder system.

Therefore, we estimate the transient depth for five different types of XBT recorder system. The investigated recorder types are Sippican MK-9 and MK-12, Z-60-16 II and III by Murayama Electric

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Co., Ltd., and MK-130 by Tsurumi Seiki Co., Ltd (TSK). Our emphasis is on the latter three types of Japanese recorder system popularly used by the Japanese oceanographic institutions, whose transient characteristics have never been reported.

2. Data

We used more than 2000 of XBT profiles by Tsurumi Seiki T-7 probes and Sippican Deep Blue (for 760 m depth measurement) for this investigation. Table 1 shows the types of recorder and probe used, and the number of casts eventually retained for the estimation.

The profiles by Tsurumi Seiki T-7 were obtained from the following two monitoring programs currently underway: Tokyo–Ogasawara Line Experiment (TOLEX; Hanawa et al., 1996) and Japan–Hawaii Monitoring Program (JAHMP). TOLEX has been operated nominally at intervals of two months since 1988 by Tohoku University and since 1993 under the collaboration with the Japan Marine Science and Technology Center (JAMSTEC). JAHMP has been undertaken since October 1998 by Tohoku University three times a year (March, June and October).

We used five recorders of three types in the two programs. All of the TOLEX-XBT data up to January 2001 were obtained by a Z-60-16 II recorder manufactured by Murayama Electric Co., Ltd. An MK-130 recorder manufactured by Tsurumi Seiki Co., Ltd., has been used since March 2001. For the JAHMP-XBT measurements, three different types of recorders were used. A Z-60-16 III recorder was used during October 1998, a Z-60-16 II recorder was used in the three cruises in 1999, and an MK-130 recorder has been used since 2000.

The profiles by Sippican Deep Blue were obtained by the SubArctic Gyre Experiment (SAGE) voluntary observing ships (VOS) program and provided by the National Oceanic and Atmospheric Administration (NOAA) via the Japan Meteorological Agency. Only the profiles taken in the North Pacific south of 35° North are used for this investigation. All of them were obtained by either MK-9 or MK-12. The total number of recorders is unknown, but if we assume that ships with different call signs used different recorder units, the numbers are not less than five and eleven for MK-9 and MK-12, respectively.

Z-60-16 II and Z-60-16 III basically employ an identical electronic circuit. Since both types contain an anti-resonance condenser with relatively large capacity, the time of their initial transient was believed to be longer than the response time of a thermistor itself (Murayama Electric Co., Ltd., personal communication). The most important difference between the two types of Z-60-16 is in the initial temperatures sensed by the circuit before entry to the water: Z-60-16 II starts from about the freezing point but Z-60-16 III is controlled to start from about 15°C. Therefore, it is expected that the time needed for the temperature difference between a thermistor and surrounding water to become small enough is shorter for Z-60-16 III than for Z-60-16 II in mid-low latitudes where SST is closer to 15°C.

MK-130 has a completely different electronic circuit from that used in the two types of Z-60-16. Its analog circuit is similar to that of MK-9 and MK-12, though its digital part (after A/D conversion) is different (Tsurumi Seiki Co., Ltd.,

Table 1
Types of XBT recorder system that are investigated here

	TOLEX		JAHMP			SAGE	
Period	1988–Jan. 2001	Mar. 2001–	Oct. 1998	1999	2000–	1998–2001	1998–2001
Recorder type	Z-60-16 II	MK-130	Z-60-16 III	Z-60-16 II	MK-130	MK-9	MK-12
Number of profiles	384	23	83	188	138	28	642

The number of profiles used is also listed for each group. The profiles by MK-9 and MK-12 were taken by five and eleven ships, respectively.

personal communication). The time constant of its whole circuit is theoretically close to that of a thermistor. Its initial (prior to the entry) temperature is also about 15°C (Tsurumi Seiki Co., Ltd., personal communication).

A thermistor installed in Tsurumi Seiki T-7 is imported from Sippican. Therefore, the characteristics (e.g. time constant) of the thermistor should be the same for both types of probe. The other part including wire and sinker are produced independently by either company, but their differences are neglected here on the assumption that the thermal response of the sensing circuit is basically determined by thermistors.

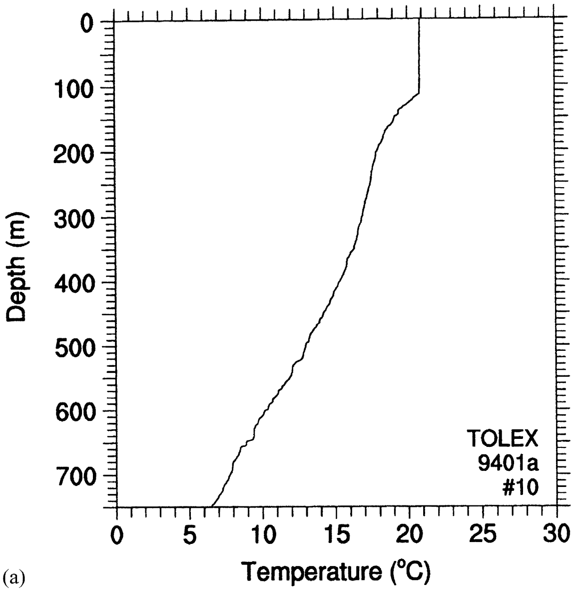
The sampling rate is 20 Hz for the three types of Japanese recorder, and 10 Hz for the Sippican recorders. The 20 Hz (10 Hz) time step corresponds to a depth increment of about 30 cm (60 cm) according to the well-accepted fall rate equation by Hanawa et al. (1995). The measured temperature is recorded to two decimal places for all of the data used. According to the information by manufacturers, the temperature resolution (digitization increment) is nearly 0.02°C (temperature dependent) for the two types of Z-60-16 and around 0.01°C for MK-130.

The five Japanese recorders, which include two Z-60-16 IIs and two MK-130s, are separately treated in the analysis. For the Sippican recorders, only the difference of type is considered.

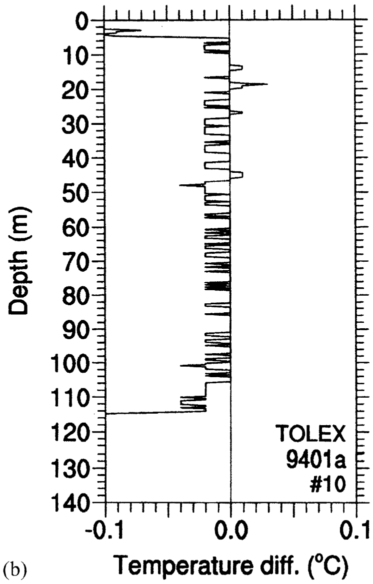
3. Method of analysis

The depth of start-up transient is estimated solely with the XBT data by using vertical uniformity of water temperature in the surface mixed layer which extends from the sea surface to occasionally more than 100 m in winter. As shown in a typical temperature profile in Fig. 1, however, the measured temperature often fluctuates within a layer that could be assumed isothermal because of digitization error. Therefore, it is very difficult to determine the isothermal layer temperature from the local temperature gradient in the vertical.

We disregard a temperature fluctuation smaller than 0.02°C and take the following procedure. First, the uppermost one hundred data points (the



(a)



(b)

Fig. 1. A typical example of (a) temperature profile and (b) its uppermost part obtained by an Z-60-16 II in January 1994 south of Honshu Island, Japan. The horizontal axis in (b) is given as temperature relative to 10 m depth. Note the spiny fluctuations (b) measured in the well-mixed layer (a).

sea surface to nearly 30 m depth) are extracted from each profile, and the first and the second mode temperatures in the layer, T_1 and T_2, are retrieved. Incomplete profiles lacking at least one data point are removed. Second, profiles are removed if $|T_1 - T_2| > 0.02$ or $F(T_1) + F(T_2) <$ 35%, where $F(T)$ is the frequency of occurrence of temperature T. A threshold of 0.02°C comes from the expected digitization error of the temperature measurement. Third, the temperature of the surface mixed layer, T_{ML}, is defined as an average of T_1 and T_2, for each of the remaining profiles. The thresholds for temperature and frequency of occurrence guarantee that the profile includes an isothermal layer of more than 10 m thickness and that its temperature is well approximated by the temperatures with the greatest frequencies of occurrence.

Fourth, profiles with initial temperature higher than T_{ML} are removed. In other words, only the profiles in which the start-up transient starts from the lower temperature side are used. If we neglect the contribution of salinity change to density variation as may be justified by using only profiles taken in the subtropical Pacific, stratification with colder water on top is unstable and actually hardly detected in the real ocean. Profiles with warmer water on top do occur, however, and it is impossible to judge if they are real or due to the transient without any supplemental information. The fourth step is taken to avoid this difficulty.

Fifth, the vertical temperature profile relative to T_{ML} is calculated for each remaining profile. Sixth, the average and the standard deviation of the relative temperature are calculated at each time of sampling. From this series of procedures, the

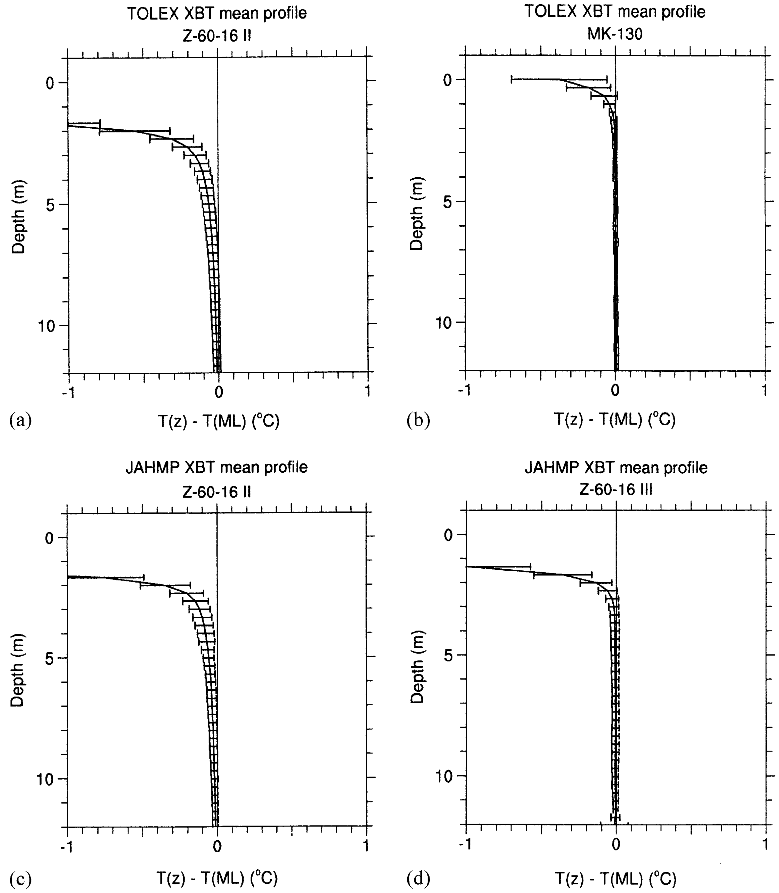


Fig. 2. Mean vertical profile and standard deviations of temperature relative to the defined mixed layer temperature, T_{ML}. See the text for details. Time-depth conversion is done by the fall-rate equation of Hanawa et al. (1995). (a) TOLEX Z-60-16 II, (b) TOLEX MK-130, (c) JAHMP Z-60-16 III, (d) JAHMP Z-60-16 II, (e) JAHMP MK-130, (f) SAGE MK-9, and (g) SAGE MK-12.

depth of the transient is estimated statistically for each recorder system.

4. Results and discussion

The mean vertical profile of temperature relative to T_{ML} is shown in Fig. 2. The standard deviations at individual times are also shown as bars. The time-depth conversion is based on the Hanawa et al. (1995) fall-rate equation.

MK-130, MK-9 and MK-12 similarly take the shortest time for the temperature adjustment, and Z-60-16 III the next. The temperature deviation becomes smaller than 0.02°C at about 2 m depth for the former three types and 3 m for the latter. In contrast, the two Z-60-16 II recorders require a much longer time for the adjustment. If the same precision criterion is applied, the value of T_{ML} is eventually obtained at 10 m depth. At 4 m depth, where the XBT temperature is recommended for the SST of the bathythermograph report, the temperature measured by Z-60-16 II is still lower than T_{ML} by nearly 0.1°C.

The behaviors of the two Z-60-16 II recorders are very similar. This can also be said for MK-130s. These facts show that the depth of the transient is the same for individuals of the same type, but basically different for different types.

The nominal precision of temperature measurement by Tsurumi seiki T-7 probes is 0.2°C. The temperature at 4 m depth measured by all of the

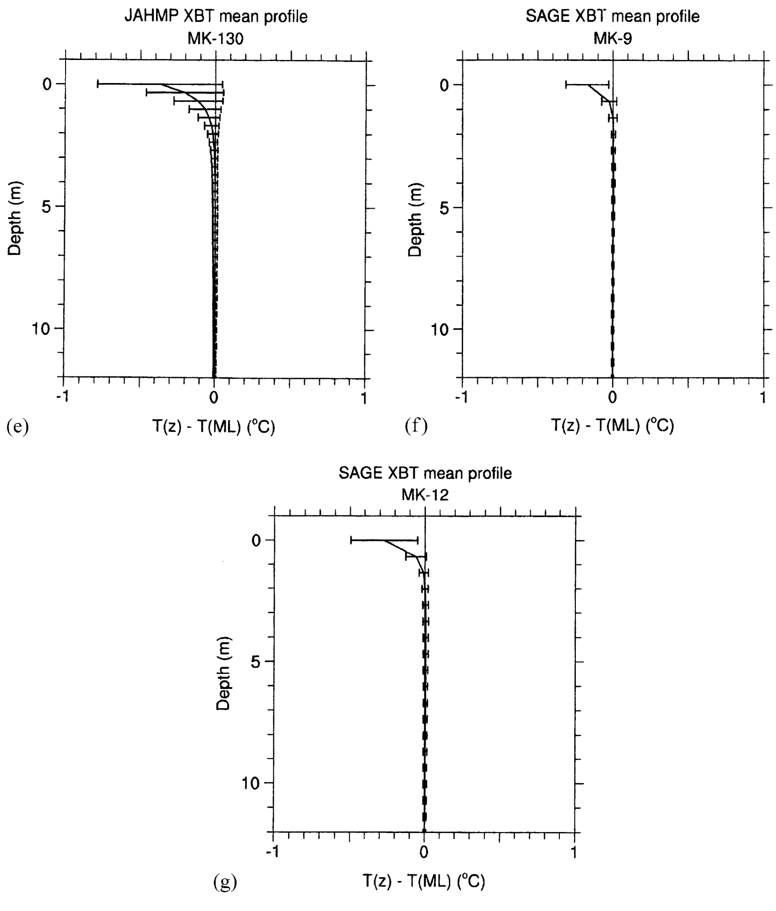


Fig. 2 (*Continued*).

tested recorders could be credited as T_{ML} (and hence the SST) within this accuracy of measurement. However, the temperature measured by Z-60-16 II at that depth is systematically lower than the water beneath by a tenth of a degree Celsius. Therefore, taking 4 m-depth temperature would result in the underestimation of SST by that amount for this case.

The effect of this underestimation to the global SST archive should be limited, since Z-60-16 II is likely used only by Japanese oceanographic institutions (including both universities and the Japan Meteorological Agency). However, it should be noted that the depth of start-up transient depends partly on the type of recorder. Therefore, recording this information as so-called "meta" data is very important for the archive.

5. Conclusions

It is concluded that the temperature measured at 4 m depth does not differ from the temperature of the underlying surface mixed layer by more than 0.2°C, the nominal temperature accuracy of Tsurumi Seiki T-7s, for all of the three Japanese recorder types and the two types of Sippican recorder we tested. The UNESCO recommendation to exclude temperatures within the uppermost 3.7 m layer in the bathythermograph report is therefore justified under this precision criterion.

However, it is shown that the depth of the start-up transient is different for different recorder types. If we take more strict constraint of an accuracy of 0.02°C, the depth of the start-up transient is estimated to be 2 m for MK-130, MK-9 and MK-12, 3 m for Z-60-16 III, and 10 m for Z-60-16 II. The temperature measured at 4 m depth by Z-60-16 II is still lower than that of the mixed layer by nearly 0.1°C. Therefore, taking the 4 m-depth-temperature as the SST in this case may cause underestimation of SST by a tenth of a degree.

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