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THE DAILY DECREASE IN WATER TEMPERATURE AROUND A SMALL ISLAND IN THE TSUSHIMA STRAIT

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CTD measurements were made during 23–24 July 1986 around Okinoshima, an isolated small island in the Tsushima Strait, where the semidiurnal and diurnal tidal currents in the southwest-northeast direction are superposed on the Tsushima Current flowing northeastward steadily. The purpose of the measurements was to clarify the mechanism of a daily decrease in water temperature in a fishing port located on the south coast of the island; this temperature decrease had been found by Takahashi et al. (1986). The results of the measurements, in conjunction with the related long-term data by Takahashi et al. (1986) and Mizuno et al. (1986), support an interpretation that the temperature decrease is caused by the intrusion of a cold water mass into the fishing port; the cold water mass upwells on the northeast side of the island when the northeastward current is strong, and then intrudes into the port when the current is reversed to flow southwestward weakly.

Key words: CTD measurement, Cold water mass, Island

1. Introduction

A cold water mass has been observed around an isolated island on stratified

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shelf seas with a strong tidal current (Simpson and Tett[1]). Formation of such a cold water mass is of oceanographical interest because of its high biological productivity, and further studies seem to be needed to clarify its formation mechanism.

Okinoshima is an isolated small island in the Tsushima Strait, where the so called Tsushima Warm Current flows northeastward; see Fig. 1. The oscillatory semidiurnal and diurnal tidal currents with the major axes of tidal ellipses lying in the direction of the Tsushima Current are superposed on this steady Current (Mizuno et al.[2]). The surrounding sea is known as a productive fishing ground in the Strait. This basalt island of an elliptical shape, with its major axis in the direction of the Tsushima Current, has a fishing port on the south coast as shown in Fig. 1. Its streamwise length, width, and area are 1.61 km, 0.83 km, and 0.70 km^2, respectively. There is a relatively shallow sea off the south coast of the island; see the isobath for 20 m in Fig. 1. The island including the shallow sea rises sharply from the flat shelf-sea bed 90 m deep up to its top 243 m high above the mean sea level. The area bounded by the isobath for 20 m may be regarded as an effective island area that directly affects the flow around the island.

Recently, Takahashi et al.[3] found that the water temperature in the Okinoshima fishing port rapidly decreases once a day, and its decrease is most prominent in July to August. Although they hinted at a relationship between this temperature variation and an internal tide, no close comparison with tidal phase variation was attempted.

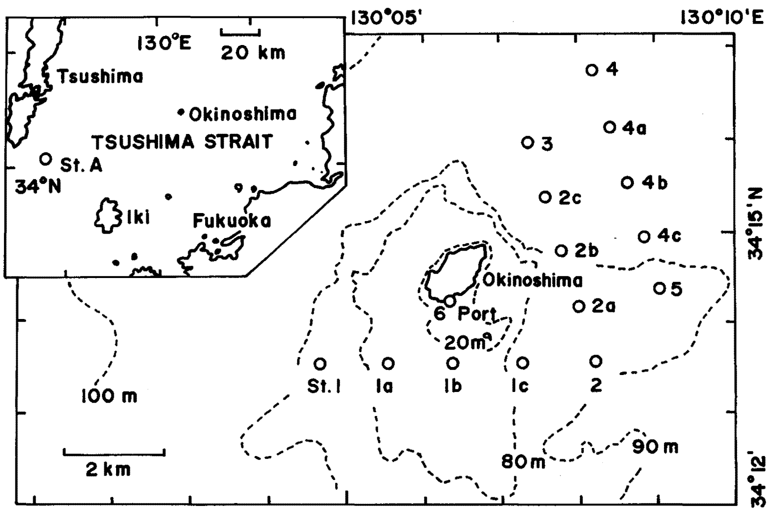


Fig. 1 Location of Okinoshima and nearby measuring stations (circles); dotted lines show isobaths.

This paper reports the results of the CTD measurements conducted around Okinoshima to clarify the mechanism of the above-mentioned daily variation of water temperature in the Okinoshima port. The previous long-term data for water temperature and current relevant to the present measurements are also used to interpret the phenomenon.

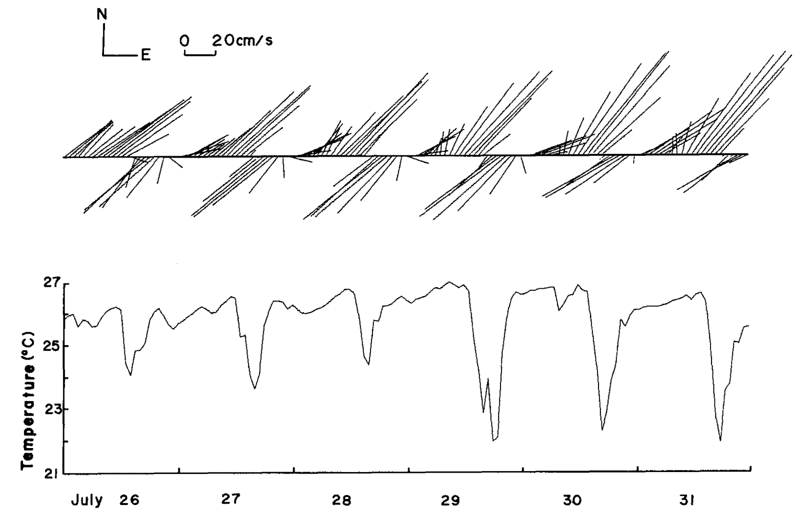


Fig. 2 Time-series data of water temperature at Okinoshima port (lower ; from Takahashi et al., 1986) and current velocity at st. A (upper ; from Mizuno et al., 1986) during 26-31 July 1984.

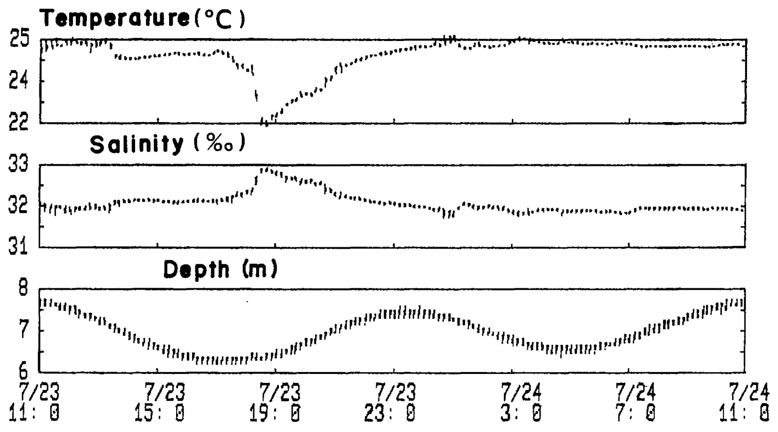
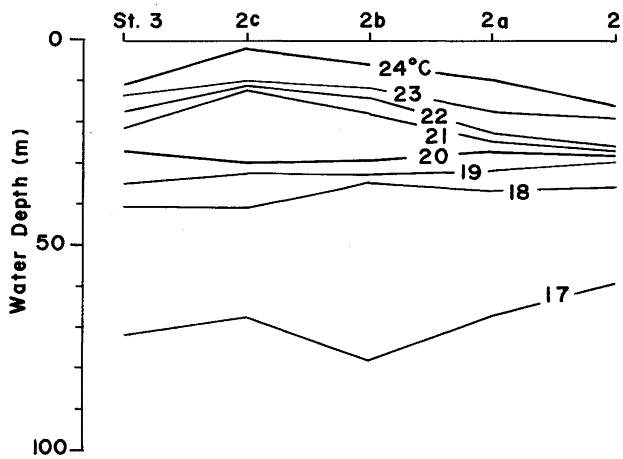


Fig. 3 Temperature, salinity, and depth variations in Okinoshima-port water for 24 hours starting from 11 : 00,. 23 July 1986.

2. Methods

CTD measurements were carried out at the stations (sts. 1-6) shown in Fig. 1 during 23-24 July 1986, using a research vessel 'Genkai' of Fukuoka Prefectural Fisheries Experimental Station. The measurements at sts. 1-5 were made by means of a CTD profiler while the ship was at each station. This profiler is a part of a newly developed self-governing profiling system (Honji et al.[4]). A 1.1 m high tripod system equipped with a set of sensors was also deployed on the 7 m-deep bottom of the port (st. 6). This system is described in Kamachi et al.[5].

(a)



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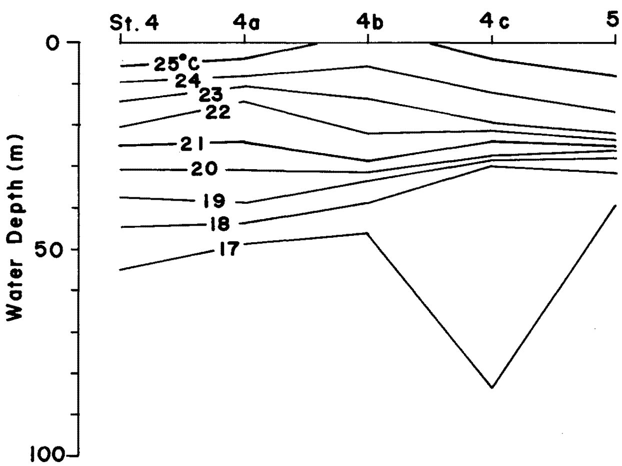
(b)



(c)

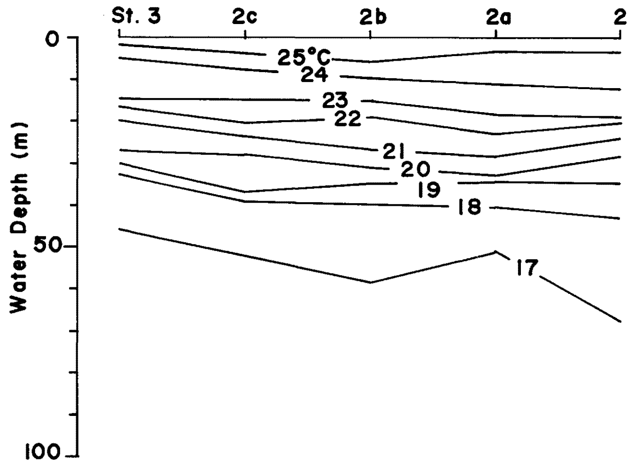


Fig. 4 Water temperature distributions in vertical planes northeast of Okinoshima on 23 July 1986; (a) 15:10-15:47 (before temperature decrease), st. 2-st. 3, (b) 16:00-16:37 (before temperature decrease), st. 4-st. 5, (c) 21:27-22:06 (after temperature decrease), st. 2-st. 3.

3. Results and discussion

A daily variation of water temperature in the Okinoshima port (Takahashi et al.[3]) and that of current velocity at 100 m depth at st. A (indicated in Fig. 1) 71 km to the west-southwest of Okinoshima (Mizuno et al.[2]) are shown in Fig. 2 for the same period of July 1984. The tidal phase at Okinoshima would be about 40 minutes behind that at st. A; this lag is neglected in Fig. 2. The northeastward current is stronger and lasts longer than the southwestward current because of the steady northeastward Tsushima Current. The rapid decrease of water temperature begins to occur at the slack waters when the current direction changes from northeast to southwest.

Figure 3 shows the temperature, salinity, and depth data taken during 23-24 July 1986 by means of the tripod system deployed on the bottom of the Okinoshima port. The water temperature decreased markedly at about 18:45 on 23 July shortly after the occurrence of the minimum water depth. The second water-depth decrease less pronounced than the first occurred about 12 hours later without accompanying the temperature decrease.

Figure 4 shows the subsurface thermal structures downstream of Okinoshima. The measurements were made during 15:10-22:06, 23 July 1986. Figure 4a shows the isothermal lines in a vertical plane lying through sts. 2 and 3 just behind the island. The isothermal lines for 20 and 24°C swell up around st. 2c, because of the formation of a lenticular water mass enclosed between the corresponding lines. This means that the cold water upwelled and the surface water around st. 2c became colder than the surrounding water during the measurements. Figure 4b shows the isothermal lines in a vertical plane lying through sts. 4 and 5, which were farther downstream of the island. The isothermal lines for 21 and 25°C form also a lenticular shape swelling up around st. 4b. The 25°C line and the sea surface line intersect around st. 4b. The measurements for the data shown in Figs. 4a and b were carried out during 15 : 10–16 : 37, 23 July 1986, before the port-water temperature decreased at about 18 : 45 on the same day. Figure 4c shows the temperature distribution in the same plane as in

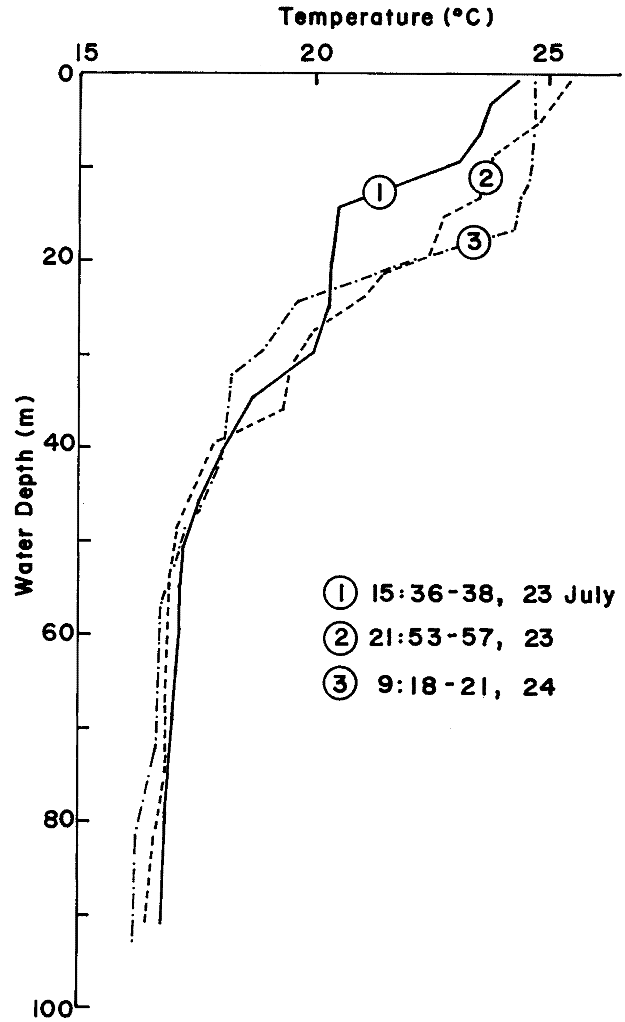


Fig. 5 Temperature profiles at st. 2c before (①) and after (②, ③) port-water temperature decrease.

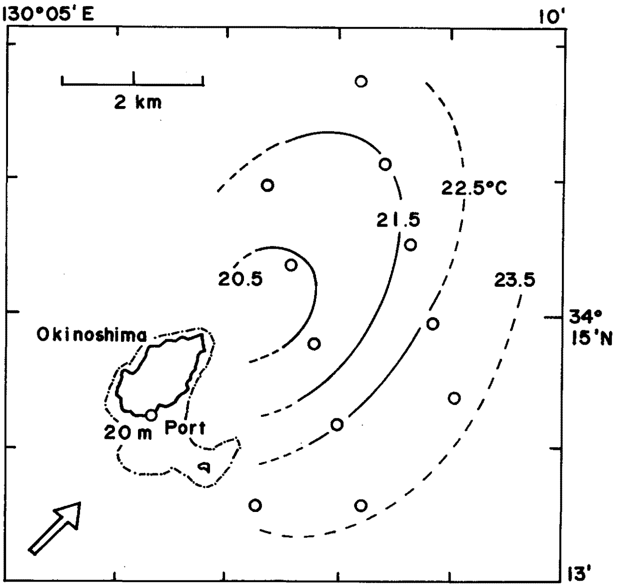


Fig. 6 Interpretative diagram for temperature distribution at 20 m depth around Okinoshima ; circles indicate stations and arrow shows direction of Tsushima Current.

Fig. 4a. These data were taken during 21 : 27–22 : 06 on the same day after the occurrence of the above-mentioned temperature decrease. The isothermal lines are nearly relaxed and show no lenticular shape.

The vertical profiles of water temperature at st. 2c are shown in Fig. 5 at three different times before and after the occurrence of the rapid decrease of the port water temperature. Although the temperature distribution in the lower layer remains almost the same, the temperature in the upper layer before the temperature decrease (solid line) is much lower than the temperature in the same layer after it (dotted and broken lines).

The distribution of water temperature at 20 m depth is shown in Fig. 6, in which four isothermal lines are drawn partly interpretatively based on the data taken during 14 : 28–16 : 35, 23 July, i. e. just before the decrease of the port-water temperature. The overall feature of the isothermal lines indicates that a cold water mass forms on the northeast side of the island. The water temperature inside this cold water mass decreases as its centre region with the lowest temperature of about 20.4°C close to st. 2c is approached.

As a mechanism for the daily decrease in water temperature at the Okinoshima port, it is inferred from the results so far described that the cold water mass which has formed on the northeast side of the island due to a strong northeastward current intrudes later into the port due to a weak southwestward current. In this connection, it is known that a starting eddy behind a body in a rotating frame is cyclonic (Boyer et al.[6]). Standing twin eddies behind a circular cylinder are also asymmetric and the cyclonic eddy is larger than the anticyclonic one (Boyer[7], and Matsuura & Yamagata[8]). The cold water mass may be formed due to an upwelling inside a similar cyclonic eddy behind the island as an obstacle in the current.

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