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Sea Surface Temperature and Surface Current in the East of Kyusyu and in the Seto Inland Sea on May of 1987

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Abstract

The sea surface temperature and the sea surface current were measured on board the Keiten Maru every 6.3 miles along the round trip cruise between Kagoshima and Takamatu on May of 1987. The transition zone between the Kuroshio and the Seto Inland Sea waters was found in the Bungo Channel. The sea surface temperature in the Kuroshio and the Seto Inland Sea were 20°-22°C and 15°C, respectively.

The horizontal gradient of temperature in the transition zone were about 0.12°C/mile on Leg 1 (outward cruise) and about 0.07°C/mile on Leg 2 (return cruise). The front was formed near the western region of the Sea of Iyo (33°-30′.0 N, 132°-08′.0 E). In the Sea of Hyuga, when the current direction is northward in the northern part, it is southward in the southern part, and when it is southward in the northern part, it is northward in the southern part.

1. Introduction

The Seto Inland Sea connects to an open sea through two large channels, one is the Kii Channel and another the Bungo Channel. The Inland Sea water exchanges mainly with the open sea water through these two channels.

YOSHIOKA[1] reported that the oceanic front exists at Kii Channel in winter. KAWAMURA *et al*[2]. investigated the hydrographic conditions and diffusion coefficient in the Bungo Channel. In 1983, several studies on the oceanic conditions and water exchange through the Kii Channel and Bungo Channels were made (YOSHIOKA[3], FUJIWARA[4], YANAGI[5]). YOSHIOKA[3] pointed out that the sea surface temperature can be used as an index of water mass in the channel.

In May of 1987, the Keiten Maru (G. T. 860 tons) of Kagoshima University had a round trip cruise between Kagoshima and Takamatu, through the Sea of Hyuga, the Bungo Channel and the Seto Inland Sea. The measurements of sea surface temperature and sea surface current on the track were carried out on board the Keiten Maru, to investigate the oceanic conditions in the East of Kyusyu and the Seto Inland Sea, and the Bungo Channel, the transition area between them.

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2. Observations of Sea Surface Temperature and Sea Surface Current

The track chart of the Keiten Maru is shown in Fig. 1. The Keiten Maru left Kagoshima on May 11, and passed through the Ōsumi Strait, the Sea of Hyuga, the Bungo Channel, the Sea of Iyo and Aki, the Mihara Strait, the Sea of Bingo and the Bisan Strait, and arrived at Takamatu on May 13. Her return cruise took on May 14 to 19 on the same course. The outward cruise and the return one are referred as Leg 1 and 2 hereafter. The distance between Kagoshima and Takamatu is about 370 nautical miles and the cruising speed of the Keiten Maru was about 12.5 knots.

The sea surface temperature (SST) has been measured with a digital thermometer (DT-3110A) manufactured by Murayama Denki Ltd. A sensor of the digital thermometer made of nickel (resistance of 100Ω) is equipped in the dome of Echo sounder under the plate keel of which depth is 3.8 meters below the sea surface. The value of water temperature was printed on the thermorecorder (R-39B) manufactured by Kaijo Denki Co. Ltd. every 30 minutes during the cruises. The distances between two measuring points was about 6.3 miles. The sea surface current (SSC) are also obtained with a DCG (Doppler Color Graph 20B) system manufactured by Kaijo Denki Co. Ltd. The numerical values of SST and SSC at each stations are tabulated in Appendix.

3. Sea Surface Temperature

3. 1. SST in the east coast of Kyusyu

Distribution of SST on the track are shown in Fig. 2.
The solid and broken lines show the surface temperature on Leg 1 and Leg 2, respectively.

SST in the East of Kyusyu has larger spatial variability. The highest temperature is 23.4°C at the Cape Sata, the mouth of Kagoshima Bay, on Leg 1 and the lowest temperature is 19.0°C at the area near the Cape Sata on Leg 2, which indicates the complicated coupling between the coastal water and the Kuroshio water. SST between the Cape Sata and Hukashima is higher than 20.0°C and has large difference between the two Legs, which indicate that SST in the region occupied by Kuroshio and its mixing water with the coastal water has large temporal variability also.

3. 2. SST in the Seto Inland Sea

The mean value of SST in each Sea and Strait of the Seto Inland Sea are shown in Table 1. It is considered that the physical factors affecting on SST in the Inland Sea is the oceanographic conditions such as the vertical tidal mixing, and inflow of fresh water from river and the meteorological conditions as the heating and cooling on the sea surface, precipitation and evaporation, wind stress and others. The overall average SST in the Seto Inland Sea was 14.7°C and the range between maximum and minimum value of SST was 3.0°C. In the Sea of Iyo, the value of SST was 13.8°C to 15.4°C with an average of 14.8°C. YANAGI[6] reported that a remarkable coastal front exists between onshore cold water from the Sea of Suo and offshore warm water from the Bungo Channel off the SE coast of the

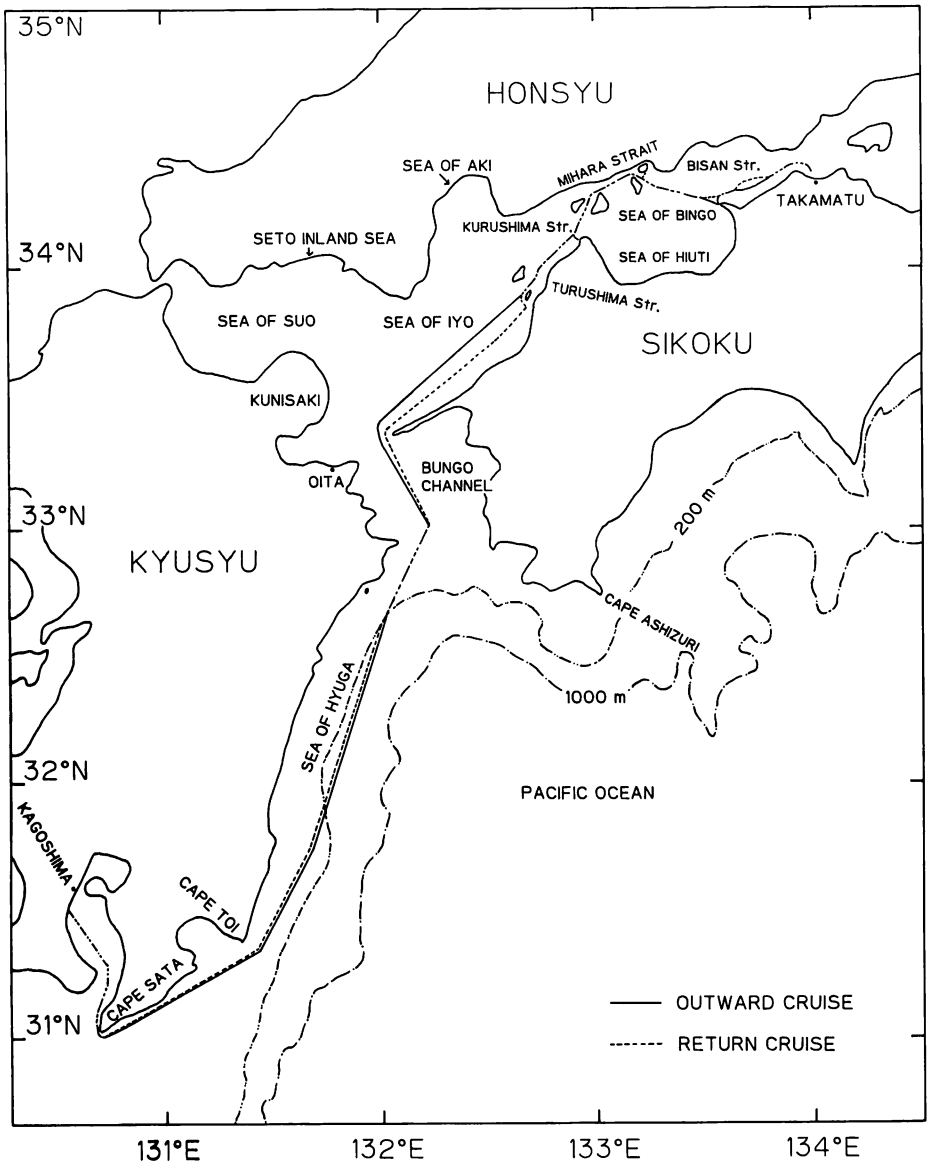

Fig. 1. Map showing the ship's track between Kagoshima and Takamatu. The solid and broken lines are outward cruise and return one. The depth contours are entered and numbers show the depth in meters.

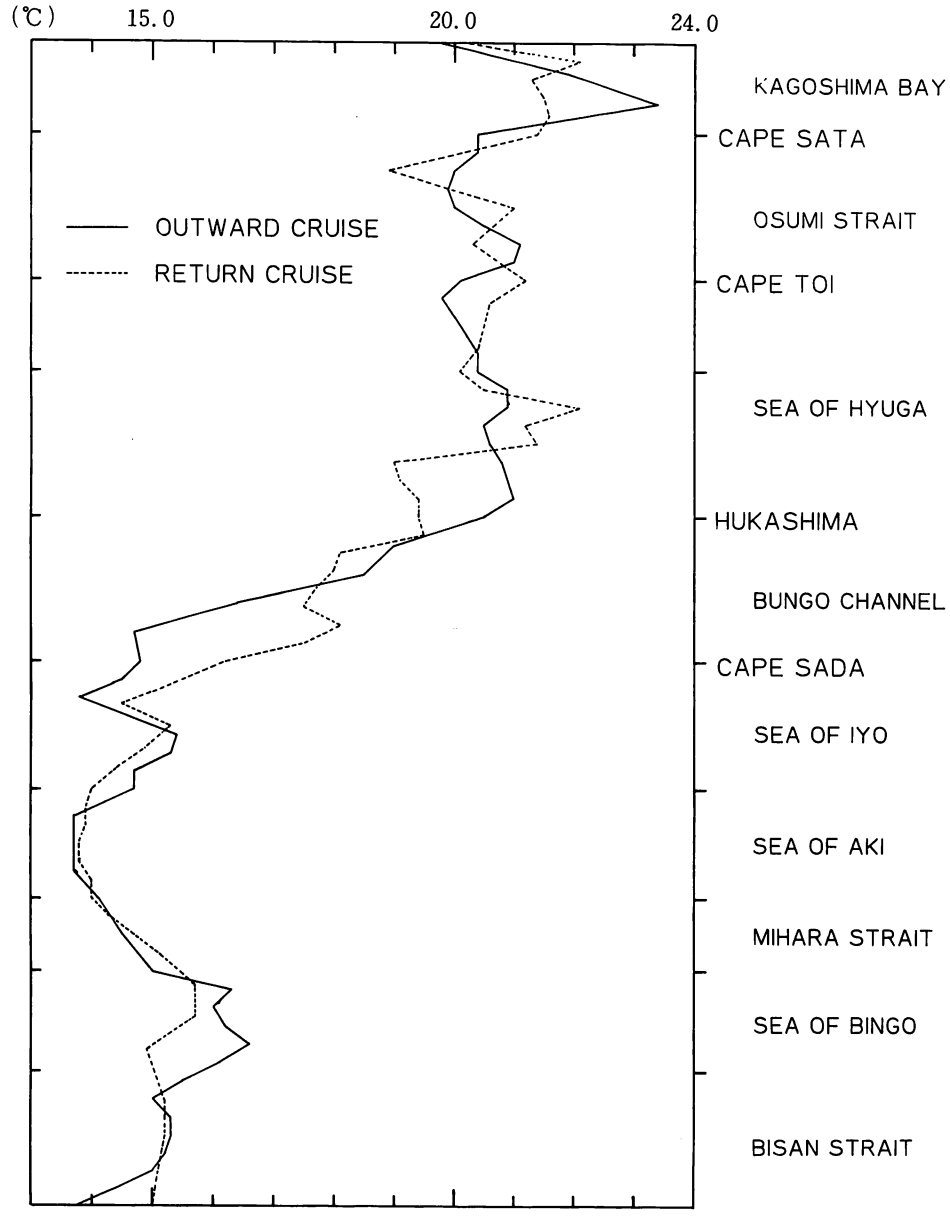

Fig. 2. Distribution of SST on the track between Kagoshima and Takamatu. The solid and broken lines are on Leg 1 (outward cruise) and Leg 2 (return cruise).

Table 1. The mean value of sea surface temperature in each Sea and the Strait of the Seto Inland Sea

	Iyo Nada	Aki Nada	Mihara Seto	Bingo Nada	Bisan Seto
Outward cruise	14.7℃	13.7℃	14.3℃	16.2℃	15.0℃
Return cruise	14.8℃	13.9℃	14.7℃	15.7℃	15.0℃

Kunisaki Peninsula in the western region of the Sea of Iyo. It should be noticed that the low temperature water was detected near 33°-30′.0 N, 132°-08′.0 E in the western region of the Sea of Iyo and its value were 13.8°C on Leg 1 and 14.5°C on Leg 2. This low temperature water may be corresponds to onshore cold water from the Sea of Suo. The front seems to be formed between the low temperature water from the Sea of Suo and the warm water from the Bungo Channel as suggested by YANAGI[6].

The Sea of Aki was occupied by the lowest temperature water with an average value of 13.8°C, because the tidal vertical mixing between the surface water and the subsurface water is strong.

On the contrary, the Sea of Bingo was occupied by the highest temperature water with an average value of 16.0°C, because the tidal current is very weak due to the water stagnant. The SST in the Bisan Strait is almost uniform in whole area due to horizontal tidal mixing. Its average value of SST was 15.0°C.

3. 3. SST in the Bungo Channel

The Bungo Channel is a transition region between the Seto Inland Sea water and the Kuroshio water in the Sea of Hyuga. SST decreases abruptly toward the Inland Sea from the Sea of Hyuga.

The temperature difference between the Inland Sea water and the Kuroshio water was 5.7°C on Leg 1 and 3.7°C on Leg 2, respectively. The horizontal gradient of temperature was about 0.12°C/mile on Leg 1 and about 0.07°C/mile on Leg 2.

It is considered that SST fluctuation is caused by many factors such as the meteorological condition, the oceanic condition with seasonal and the short term variation of distance of the Kuroshio axis from the coast. In the present observation, the observed currents were about 1.5 knots with the northward direction on Leg 1 and about 0.7 knots with the southward direction on Leg 2, respectively. In addition, the mean wind direction and speed were from south to north, about 7 m/sec on Leg 1 and from north to south about 5 m/sec on Leg 2. The sharp SST fluctuation on Leg 1 compared with on Leg 2 may be attributed by the strong northward current of the Kuroshio water and the wind from the south.

4. Sea Surface Current

Sea surface current on Leg 1 and Leg 2 are shown in Fig. 3(a) and (b), respectively. In the Ōsumi Strait, the current flows toward WSW with speed of 1.9 knots on Leg 1 and ENE with speed of 1.4 knots on Leg 2, respectively. At the mouth of Sibusi Bay, offshore current with speed of about 0.5 knots, was found on Leg 1 but was not on Leg 2.

On Leg 1, the current flows toward SSW with speed of 0.7 knots along the coast off Nitinan in the southern side of Miyazaki and the current flows toward NNE with speed of 0.4 knots along the coast in the northern side of Miyazaki. Off Nobeoka, the current flows eastward with about 0.7 knots and off Hukashima northward with about 0.4 knots, respectively. On Leg 2, the current flows toward NNE with speed of 0.2-1.0 knots along the coast between the Cape Toi and off Hyuga. The counter current existed with direction of SSW-SSE and speed of about 1.0 knot off Hyuga. The existance of coastal counter current was revealed off Nobeoka (Ichikawa *et al.*). The current toward the shore with direction of NW and speed of about 0.6 knots existed off Hukashima.

The current largely depends tidal phase in the Bungo Channel. The current flows toward NNW with speed of 1.3-1.8 knots on Leg 1 and SSE with speed of about 0.7 knots on Leg 2.

5. Summary

The continuous measurements of SST and SSC were analyzed by using the data observed on board the Keiten Maru on a cruise between Kagoshima and Takamatu on May of 1987. The following results were obtained ;

1) The high temperature water, having the value of more than 20.0°C, exists in the Sea of Hyuga, which indicates that the region is occupied by mixing water of the coastal water with the Kuroshio water.
2) The low temperature water, having the value of about 15.0°C, exists in the Seto Inland Sea and SST is almost uniform overall except that in the Sea of Bingo.
3) In the Bungo Channel, the temperature difference between the Kuroshio water and the Seto Inland Sea water was about 5.0°C and larger on outward cruise than on return one.
4) The front was formed near the western region of the Sea of Iyo between the cold water from the Sea of Suo and the warm water from the Bungo Channel.
5) In the Sea of Hyuga (including the Bungo Channel), the current system is different in the northern part and the southern one, i.e., when the current direction is northward in the northern part, it is southward in the southern part. On the contrary, when it is southward in the northern part, it is northward in the southern part.

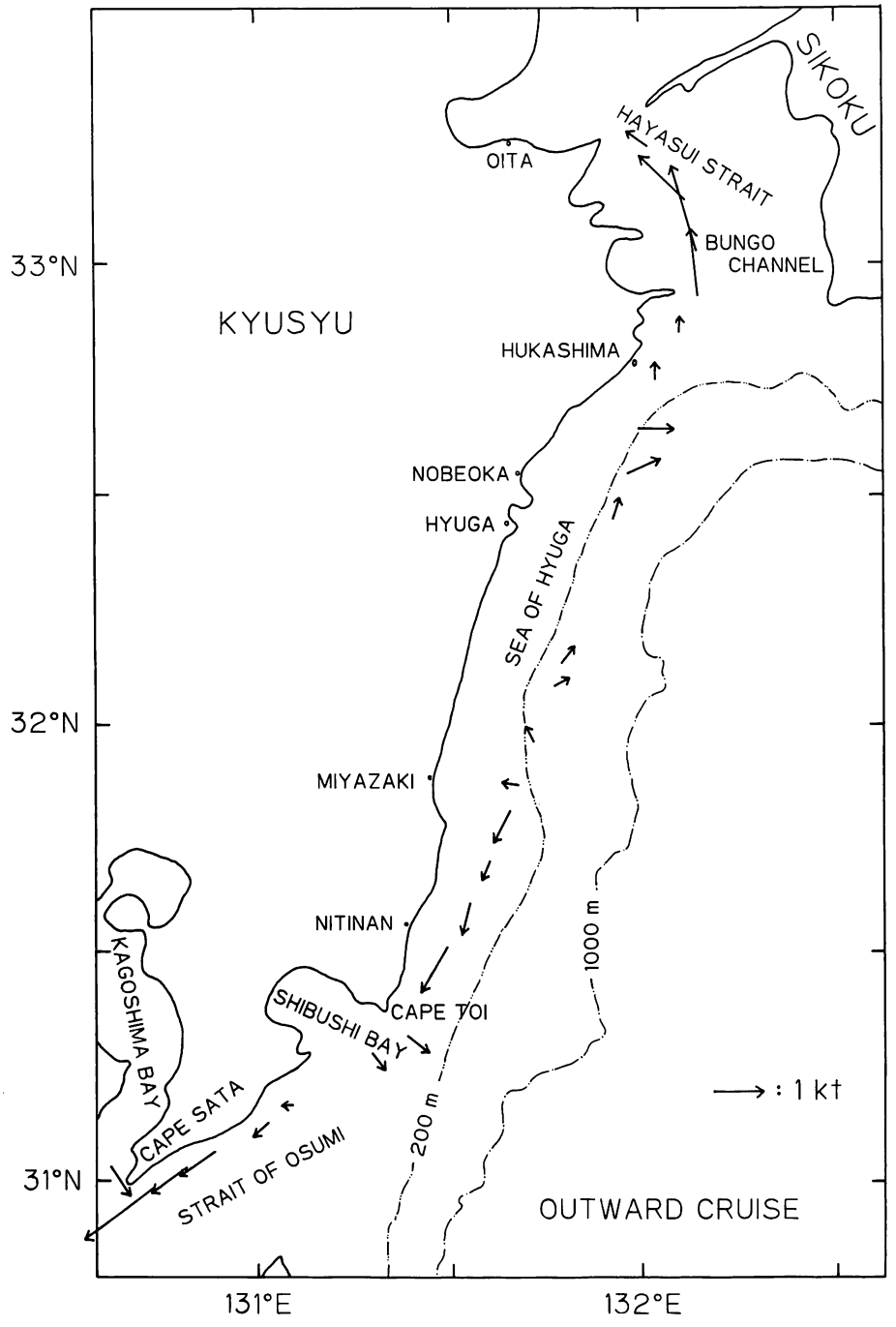

Fig. 3. Sea surface current obtained by DCG (Doppler Color Graph) in the East of Kyusyu on Leg 1 (a) and Leg 2 (b).

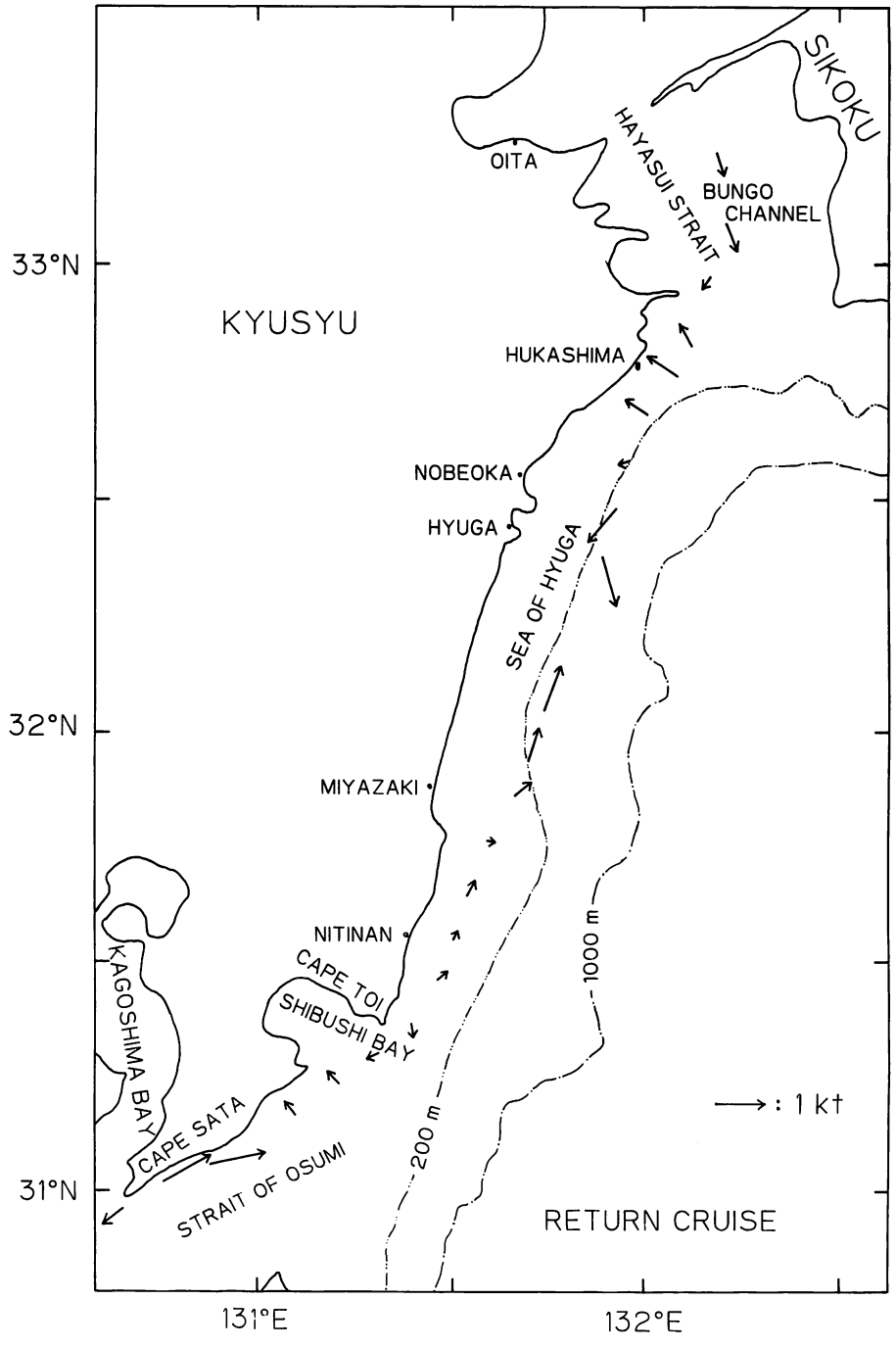
SIKOKU
OITA
HAYASUI STRAIT
BUNGO CHANNEL
33°N
KYUSYU
HUKASHIMA
NOBEOKA
HYUGA
SEA OF HYUGA
32°N
MIYAZAKI
NITINAN
CAPE TOI
SHIBUSHI BAY
KAGOSHIMA BAY
CAPE SATA
STRAIT OF OSUMI
200 m
1000 m
: 1 kt
31°N
RETURN CRUISE
131°E
132°E

Fig. 3. (b).

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Appendix Table

Date	Time	Position		Water	Current	
		latitude (N)	longitude (E)	temperature (℃)	direction	speed (knot)
5/11	1417	31°−30′.2	130°−32′.3	19.8	—	—
〃	1530	31°−18′.4	130°−42′.1	21.9	13°	0.5
〃	1700	31°−01′.6	130°−37′.8	23.4	148°	0.7
〃	1730	30°−58′.9	130°−41′.0	20.4	231°	1.9
〃	1800	31°−01′.8	130°−47′.7	20.0	233°	1.0
〃	1830	31°−04′.9	130°−53′.9	19.9	237°	0.8
〃	1900	31°−08′.1	131°−06′.2	20.0	218°	0.6
〃	1930	31°−10′.5	131°−05′.0	20.5	265°	0.3
〃	2000	31°−13′.8	131°−11′.7	21.1	—	—
〃	2030	31°−16′.9	131°−18′.1	21.0	143°	0.4
〃	2100	31°−19′.5	131°−23′.3	20.1	125°	0.6
〃	2130	31°−25′.3	131°−26′.9	19.8	211°	0.3
〃	2200	31°−31′.2	131°−30′.1	20.0	211°	0.6
〃	2230	31°−37′.0	131°−33′.6	20.2	193°	0.7
〃	2300	31°−42′.4	131°−36′.8	20.4	200°	0.6
〃	2330	31°−48′.8	131°−39′.9	20.4	206°	0.7
5/12	0000	31°−52′.4	131°−41′.2	20.9	275°	0.4
〃	0030	31°−58′.2	131°−43′.6	20.9	327°	0.3
〃	0100	32°−05′.0	131°−46′.3	20.5	64°	0.5
〃	0119	32°−08′.1	131°−47′.5	20.6	41°	0.4
〃	0149	32°−13′.4	131°−49′.8	20.8	—	—
〃	0219	32°−20′.4	131°−52′.6	20.9	—	—
〃	0249	32°−26′.5	131°−55′.0	21.0	8°	0.5
〃	0319	32°−32′.7	131°−57′.5	—	66°	0.8
〃	0349	32°−38′.2	131°−59′.6	20.5	95°	0.6
〃	0419	32°−44′.7	132°−02′.5	—	2°	0.4
〃	0449	32°−50′.7	132°−05′.9	—	4°	0.4
〃	0519	32°−56′.6	132°−08′.7	19.0	352°	1.5
〃	0549	33°−02′.3	132°−08′.6	18.5	343°	1.8
〃	0619	33°−09′.2	132°−05′.9	16.4	314°	1.3
〃	0649	33°−15′.3	132°−01′.2	14.7	305°	0.5
〃	0719	33°−20′.8	131°−59′.0	14.8	36°	2.1
〃	0749	33°−25′.7	132°−02′.9	14.5	84°	0.5
〃	0819	33°−30′.0	132°−08′.9	13.8	77°	0.6
〃	0849	33°−34′.2	132°−14′.5	14.6	58°	0.1
〃	0919	33°−39′.8	132°−19′.6	15.4	65°	0.1
〃	0949	33°−43′.4	132°−24′.7	15.3	294°	0.1
〃	1019	33°−48′.2	132°−30′.8	14.7	201°	0.3
〃	1049	33°−52′.4	132°−35′.6	14.7	211°	0.3
〃	1119	33°−56′.5	132°−41′.1	—	220°	0.7
〃	1149	34°−00′.8	132°−45′.8	13.7	215°	2.1

Date	Time	Position		Water temperature (℃)	Current	
		latitude (N)	longitude (E)		direction	speed (knot)
5/12	1219	34°−05′.0	132°−50′.3	13.7	234°	1.4
〃	1249	34°−10′.3	132°−54′.9	—	237°	2.5
〃	1319	34°−15′.8	132°−57′.9	13.7	193°	1.1
〃	1349	34°−18′.3	132°−59′.2	14.1	247°	2.9
〃	1419	34°−21′.4	133°−06′.2	14.5	244°	3.9
〃	1449	34°−24′.2	133°−11′.3	15.0	273°	2.2
〃	1519	34°−20′.9	133°−17′.2	16.3	277°	0.5
〃	1532	34°−20′.4	133°−20′.2	16.0	—	—
〃	1632	34°−15′.9	133°−31′.3	16.6	231°	0.6
〃	1702	34°−15′.2	133°−33′.9	16.1	148°	0.5
5/13	0521	34°−16′.9	133°−34′.7	15.5	—	—
〃	0537	34°−17′.6	133°−38′.3	15.0	—	—
〃	0607	34°−19′.9	133°−45′.2	15.3	—	—
〃	0613	34°−20′.4	133°−46′.4	15.3	—	—
〃	0643	34°−23′.4	133°−52′.8	15.2	238°	1.9
〃	0713	34°−25′.8	133°−59′.5	15.0	251°	1.9
〃	0743	34°−26′.2	134°−02′.8	—	234°	1.3
〃	0813	34°−26′.2	134°−09′.8	14.4	289°	1.4
5/14	0930	34°−25′.3	134°−01′.3	15.0	259°	2.0
〃	1000	34°−23′.4	133°−54′.5	15.1	269°	0.4
〃	1030	34°−21′.4	133°−47′.2	15.2	—	—
〃	1100	34°−18′.8	133°−40′.4	15.2	—	—
〃	1230	34°−19′.4	133°−22′.6	14.9	—	—
〃	1300	34°−23′.4	133°−21′.8	15.7	—	—
5/15	0630	34°−22′.5	133°−13′.8	15.7	—	—
〃	0700	34°−22′.3	133°−09′.6	15.1	169°	0.2
〃	0730	34°−19′.0	133°−04′.0	14.7	46°	0.8
〃	0800	34°−16′.9	132°−57′.0	14.3	89°	0.6
〃	0830	34°−11′.2	132°−54′.7	14.0	23°	1.5
〃	0900	34°−05′.9	132°−50′.7	14.0	52°	1.7
〃	0930	34°−01′.9	132°−46′.2	13.8	50°	1.5
〃	1000	33°−57′.2	132°−42′.0	13.8	39°	2.0
〃	1030	33°−53′.5	132°−36′.4	13.9	51°	0.8
〃	1100	33°−51′.4	132°−39′.6	13.9	102°	0.1
5/16	0430	33°−52′.3	132°−40′.6	14.0	60°	0.2
〃	0500	33°−48′.9	132°−36′.9	14.4	219°	0.8
〃	0530	33°−44′.2	132°−32′.0	—	230°	0.5
〃	0600	33°−39′.6	132°−26′.2	14.9	346°	0.1
〃	0630	33°−36′.0	132°−21′.0	15.3	308°	0.2
〃	0700	33°−31′.4	132°−13′.3	—	41°	0.4

Date	Time	Position		Water	Current	
		latitude (N)	longitude (E)	temperature (℃)	direction	speed (knot)
5/16	0730	33°−27′.1	132°−07′.9	14.5	44°	0.8
〃	0800	33°−23′.2	132°−02′.3	15.4	65°	1.4
〃	0830	33°−18′.7	131°−59′.4	16.2	289°	3.0
〃	0900	33°−17′.1	132°−06′.1	−	322°	0.7
〃	0930	33°−16′.5	132°−13′.2	17.5	291°	0.3
〃	1000	33°−15′.5	132°−19′.4	18.1	113°	0.5
5/18	0600	33°−14′.4	132°−20′.2	17.5	177°	0.6
〃	0630	33°−11′.0	132°−14′.5	17.7	160°	0.6
〃	0700	33°−04′.7	132°−12′.5	18.0	152°	0.7
〃	0730	32°−58′.8	132°−10′.3	18.1	212°	0.4
〃	0800	32°−52′.7	132°−07′.0	19.5	329°	0.6
〃	0830	32°−46′.2	132°−04′.0	19.4	301°	0.6
〃	0900	32°−40′.6	132°−00′.6	19.4	300°	0.5
〃	0930	32°−34′.9	131°−58′.1	19.1	255°	0.2
〃	1000	32°−28′.7	131°−55′.6	19.0	216°	0.9
〃	1030	32°−22′.6	131°−53′.5	−	162°	1.1
〃	1100	32°−15′.9	131°−48′.8	21.4	−	−
〃	1130	32°−09′.9	131°−46′.5	21.2	−	−
〃	1200	32°−02′.8	131°−44′.8	22.1	20°	1.0
〃	1230	31°−56′.8	131°−42′.2	−	15°	0.8
〃	1300	31°−51′.7	131°−40′.1	20.5	53°	0.4
〃	1330	31°−45′.5	131°−36′.4	20.1	105°	0.2
〃	1400	31°−39′.4	131°−33′.6	20.4	26°	0.5
〃	1430	31°−33′.5	131°−30′.8	20.5	27°	0.2
〃	1500	31°−27′.6	131°−28′.1	20.6	52°	0.2
〃	1530	31°−21′.9	131°−23′.9	21.2	166°	0.3
〃	1600	31°−17′.9	131°−18′.3	−	243°	0.2
〃	1630	31°−14′.2	131°−12′.3	−	312°	0.3
〃	1700	31°−10′.7	131°−05′.4	20.3	326°	0.2
〃	1730	31°−07′.0	130°−59′.3	−	331°	0.1
〃	1800	31°−03′.4	130°−52′.9	21.0	75°	1.4
〃	1830	31°−00′.1	130°−46′.4	−	58°	1.4
〃	1900	30°−57′.7	130°−39′.5	18.9	229°	0.5
〃	1930	31°−00′.3	130°−36′.4	21.4	217°	0.3
〃	2000	31°−06′.7	130°−40′.5	21.6	40°	0.2
〃	2030	31°−11′.3	130°−45′.3	21.5	345°	0.5
5/19	0800	31°−14′.2	130°−43′.4	21.3	213°	0.3
〃	0830	31°−19′.9	130°−40′.4	−	155°	0.3
〃	0900	31°−25′.2	130°−36′.8	22.1	298°	0.1
〃	0930	31°−30′.0	130°−33′.1	20.2	15°	0.2