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Article spécial n° 6

The role of cryptozoology in achieving an exhaustive inventory of the marine fauna*

Paul H. LEBLOND**

The Sea has played a vital role in the development of many areas of Science. Its rich and varied fauna has provided naturalists with clues from which they have been able to make sense of the diversity of life. The shape of the ocean basins and of the great ridges which traverse them has led to the development of plate tectonics and to a new understanding of the Earth's crust.

In recent years, there has been increased emphasis on the exploitation of the Ocean, with concerns focusing on the quantitative aspects of marine biology. Questions such as "How many?" rather than "What kind?" of marine organisms have come to the fore.

Have we now perhaps left behind the Age of Exploration to enter that of Exploitation of the Sea? Not entirely. The ocean depths retain much of their mystery and continue to attract daring explorers and broad public interest. Millions thrill with Jacques Cousteau in watching an undersea world where there always seems to be something new to be discovered.

But, is there *really* anything worthwhile left to be discovered in the ocean? In this age of electronic in-situ sampling, deep-diving submersibles, remote sensing and computer modelling, can there be anything *significant* left to find? Have we not by now explored the oceans widely and thoroughly enough that only matters of detail or of complexity need be settled?

Most oceanographers would argue that our knowledge of the oceans is still incomplete and superficial, that much remains to be discovered and clarified in flow dynamics, fish behaviour, ecological relationships, tectonic processes, climatic mechanisms, etc... Thousands of marine scientists around the world wouldn't be exploring and studying the ocean with such dedication if they did not believe that something important remains to be discovered!

One should thus have little difficulty in convincing a scientific audience that great discoveries are still to be made in many fields of marine sciences. To explore the broader aspects of future discovery in marine sciences is however a challenge which I will leave for some other occasion. Rather, I have selected a more specific, and more controversial question which exemplifies many of the points related to the anticipation of potential discovery.

The question asked here is the following: Are there any important elements of the marine fauna left to be discovered? In other words, are there still any large, or new, or unexpected animals in the oceans which remain to this day unknown to science? And if so, how many?

Many have answered the general question in the affirmative, and some, like HEUVELMANS (1983), have even ventured to extrapolate from historical rates of discovery

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to obtain an estimate of the number of future discoveries to be expected. Let us refrain from searching for a definite answer to the question: we cannot positively know that there are undiscovered animals until they are actually found, identified and categorized to the general satisfaction of the scientific community. Asking the question nevertheless forces us to consider the process whereby new elements of the marine fauna are become known to science.

Most, if not all, marine animals have been discovered by accident, through man's efforts at fishing. As its diversity has revealed itself, the marine fauna has been catalogued and apportioned in families, classes and phyla. As in other areas of science, improvements in sampling and harvesting methods have led to unsuspected discoveries: new animals have been added to the marine bestiary. Deep submersibles, for example, have made detailed visual exploration of the ocean floor possible, leading to the discovery of a completely unexpected fauna near deep sea thermal vents. PARSONS (1985) has emphasized the need to explore for the sake of discovery in order to broaden our knowledge of the oceans. His remarks apply directly to the discovery of new marine creatures.

Occasionally, there have also occurred significant and surprising discoveries unrelated to the development of new observational methods. The coelacanth, *Latimeria chalumnae*, had already been fished up many times from the mid-depths of the Indian Ocean by Comoro Island natives before a specimen came to the attention of Marjorie Courtenary-Latimer in 1938 (SMITH, 1956; COURTENARY-LATIMER, 1979). Because of its kinship to primitive fishes known only from the fossil record, its modern discovery attracted considerable attention. The megamouth shark, *Megachasma pelagios*, (TAYLOR *et al.*, 1983) on the other hand did not have a fossil pedigree. The first specimen was brought up in 1976 tangled in the anchor chain of a US Navy ship in Hawaii. Two more specimens have since been found, one off California, the other off western Australia, suggesting a global distribution (ISC, 1988).

In the face of such unexpected discoveries, and considering the prospects for improvement in techniques of observing and sampling the oceans, it would seem presumptuous to declare that no further discoveries are to be expected. We are thus back to the question: "How many?"

One might argue that on the time scale of modern scientific discovery, there is a fixed and finite number of animal species in the oceans. The more have been discovered, the less there remains to be found. That is however of little use since the total remains unknown, and hence so does the residue. Beyond the arguments of plausibility based on expectations of better sampling and on past accidental discoveries, there are however observations which point towards the possibility of additional discoveries and give hints as to their nature.

A definite addition to the fauna is made by catching an animal. But what if the animal is only seen, not caught? How do we account for those that get away? Most zoologists would rather discard near misses and wait until a tangible type-specimen is available to pronounce on species and genus. Until caught, a creature remains a rumour, an unconfirmed visual observation, not yet the object of zoology, but rather that of **cryptozoology**.

The term **cryptozoology** was coined by the French zoologist Bernard Heuvelmans in the 1950's (HEUVELMANS, 1982) to describe the study of creatures which are known only through visual or incomplete material evidence. Such animals are also called cryptids, a more appropriate term than monsters; the term is usually reserved for rather large creatures, observable at sea without instrumentation. Cryptids are often well known to natives before attracting the attention of science: such was the case for the coelacanth. Sometimes scientists are awarded a fleeting glimpse of an animal which they can only describe without being able to collect a specimen. This is what happened to MEADE-WALDO and NICOLL (1906) as they saw an unidentified marine animal with a long neck and a large dorsal fin swim past their ship off the coast of Brazil.

Cryptids provide a clue of what is to be expected in terms of future discoveries, at least for rather large animals. Indeed some erstwhile cryptids have already graduated to zoological acceptance. There are many examples on land: the gorilla, the okapi, the platypus. A marine example is the giant squid *Architeuthis*, the Kraken of Norse mythology, now known from many strandings.

So, what does cryptozoology tell us? HEUVELMANS (1986) has brought together a checklist of unknown animals, the result of three decades of research on eye-witness reports. Marine cryptids figure prominently. What follows is drawn from HEUVELMANS' (1986) list; further documentation if found in HEUVELMANS (1968).

Unconfirmed cetaceans lead the list of marine animals for which no specimens have been captured. A high-finned sperm-whale, 60 feet in length, is said to have been frequently seen around the Shetland Islands in the 17th century. It is reported by Sir Robert Sibbald, and described by him as *Physeter tursio* (HEUVELMANS, 1986). Another long-finned whale, 20-30 feet long, was reported by WILSON (1907) who saw three specimens in January 1902 and four more the following month while on Robert Scott's *Discovery* expedition in the Antarctic.

It is not surprising to find a possible new species of beaked whales in the list. A number of beaked whales, the Mesoplodons in particular (WATSON, 1981), are known only from a few strandings and are difficult to identify at sea. HEUVELMANS (1968) quotes P.H. Gosse as having watched a school of 30 ft long, yet unidentified whales, black above and white below, in the North Atlantic over a century ago.

HEUVELMANS also includes a new kind of killer whale, entirely sepia brown with star-shaped scars, sighted several times in the Gulf of Aden by MORZER BRUYNS (1971). The same author mentions three dolphins, one from the Mediterranean, one from the coast of Senegal, and one from the Philippines. A black and white spotted dolphin with *two* dorsal fins has also been reported from the Mediterranean and from the Southern Ocean (HEUVELMANS, 1968).

Tales of less conventional creatures are also to be expected: the undiscovered is bound to be strange. "Mermaids" and "mermen" are mentioned by HEUVELMANS (1986) as having been frequently reported from areas where no recent species of sirenians are known to have lived during historical times. Rumours of survival of Steller's sea-cow (*Hydrodamalis gigas*) continue to be heard along the Bering Sea shores. Both MACKAL (1980) and HEUVELMANS mention the "sea-ape", a creature seen off the Aleutian Islands by Steller in 1741.

Reports of large, mostly elongated marine animals usually referred to as sea-serpents have been classified by HEUVELMANS (1968) into seven categories corresponding to their morphological characteristics: the super-otter, the many-humped sea-serpent, the long-necked sea-lion, the merhorse and a many finned, armoured archeocete—all mammals—with a huge ocean-dwelling saurian and a large eel-like fish in addition. HEUVELMANS examined over 600 reports to arrive at his classification. A more localized survey on the western coast of North America (LEBLOND and SIBERT, 1973) identified three types of marine cryptids: two of them variants of Heuvelmans' merhorse, the other an elogated creature, all three apparently air breathers and mammalian.

Finally, there are the reports of giant octopus, focusing on a mysterious standing on a Florida beach at the end of the last century (see also MACKAL, 1980).

If only a fraction of these reports is based on fact, there remains a rich harvest of discovery of major faunistic elements in the world ocean. However, because all these observations are based only on eye-witness reports and cannot be backed by tangible specimens, their status remains doubtful. Cryptozoological evidence is subjective and non-reproducible. While there is no a priori reason to reject as fanciful every shred of visual information, the scientific method has gained respect as a method of arriving at universally accepted truths precisely because it deals with objective and reproducible evidence. Cryptozoology should thus perhaps be seen as a precursor of zoology, arriving at its conclusions earlier, but with less confidence. One should thus not conclude that the various cryptids glimpsed in the sea must all be discovered some day; some may, others may not. Cryptozoology only provides clues as to what may yet be confirmed; it is like a road map based on hear-say: better than nothing, but not entirely to be trusted.

Cryptozoological information should thus be seen as an adjunct to zoological discovery; not a body of information which is to be believed or disbelieved, but a collection of indices which should not be ignored and which may inspire and guide marine scientists in their effort to complete the inventory of the larger elements of the marine fauna. There is no such guide for small or microscopic creatures, where the need for exploratory research is even more acute.

References

COURTENARY-LATIMER, M. (1979): My story of the first coelacanth. p. 6-10. *In*: J.E. McCOSHER and M.D. LAGIOS, ed., The Biology and Physiology of the Living Coelacanth. Calif. Acad. Sci. Occas. Paper No. 134.

HEUVELMANS, B. (1968): In the Wake of the Sea-Serpents. Hill and Wang, New York. 645 pp.

HEUVELMANS, B. (1982): What is cryptozoology. Cryptozoology, **1**, 1-12.

HEUVELMANS, B. (1983): How many animal species remain to be discovered? Cryptozoology, **2**, 1-24.

HEUVELMANS, B. (1986): Annotated checklist of apparently unknown animals with which cryptozoology is concerned. Cryptozoology, **5**, 1-26.

ISC (1988): Third Megamouth Found. Internat. Soc. of Cryptozoology Newsletter, **7** (4), 4.

LEBLOND, P.H. and J.R. SIBERT (1973): Observations of large unidentified marine animals in British Columbia and adjacent waters. Dept. of Oceanogr., Univ. of British Columbia, M.S. Report 28. 64 pp.

MACKAL, R. (1980): Searching for Hidden Animals: an Inquiry into Zoological Mysteries. Doubleday, New York.

MEADE-WALDO, E.G.B. and M.J. NICOLL (1906): Description of an unknown animal seen at sea off the coast of Brazil. Proc. Zool. Soc. Lond., **2** (68), 719.

MORZER BRUYNS, W.F.J. (1971): Field Guide of Whales and Dolphins. C.A. Mees, Amsterdam.

PARSONS, T.R. (1985): Hypothesis testing and rigorous statistics as criteria for marine research proposals. La mer, **23**, 109-110.

SMITH, J.L.B. (1956): Old Fourlegs. Longmans, Green and Co. 260 pp.

TAYLOR, L.R., L.J.V. COMPAGNO and P.J. STRUHSAKER (1983): Megamouth - A new species, genus, and family of lamnoid sharks (*Megachasma pelagios,* Family Megachasmidae) from the Hawaiian Islands. Proc. Calif. Acad. Sci., **43**, 87-110.

WATSON, L. (1981): Sea Guide to Whales of the World. Dutton, New York. 302 pp.

WILSON, E.A. (1907): Antarctic Mammalia. *In*: National Antarctic Expedition, Natural History. London, **2**, 4-5.

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Internal tidal waves and internal long period waves in the Sanriku coastal seas, eastern coast of northern Japan*

Moriyoshi OKAZAKI**

Abstract: The study of internal tidal waves in a bay was carried out on the basis of observed records in Toni Bay (located in the northeastern area of Honshu) in autumn 1984.

a) It was found that the internal tidal waves were predominant and appeared intermittently with a duration of several days in the bay. On the basis of T-S diagram analyses, it was suggested that the intermittency of the internal tidal waves in the bay was closely related to the intermittent vertical displacement of the offshore thermocline.

b) The cause of the intermittent vertical displacement of the thermocline was investigated by analyzing subsurface water temperature at two bays and the variation of sea surface level anomaly (local difference of tidal deviations) among three bays adjacent to Toni Bay. From the analysis of the variation of the thermocline depth, some evidence was obtained for the existence of internal long period waves propagating southward along the coast. The intermittent appearance of the internal tidal wave in the bay occurred from the superposition of the internal tidal wave propagating onshore and the internal long period wave propagating alongshore. Moreover, it is suggested that the internal long period waves are related to the behaviour of an offshore density front at the sea surface in Sanriku coastal seas.

c) The internal tidal waves of semidiurnal period in the bay were likely related to the 2nd mode of the offshore internal tidal waves from comparison of the dispersion relations of the internal tidal waves in the bay with those out of the bay and from the simple model estimation of an energy efficiency of the offshore internal tidal waves propagating into the bay.

1. Introduction

In reports on observations of internal tidal waves, the intermittency of occurrence of internal tidal waves has been noted only recently. In the open ocean, the internal tidal waves are found as predominant semidiurnal fluctuations of the current velocity in several subsurface depths. For example, WUNSCH (1975) quoted from MAGAARD and MCKEE (1973) and indicated that the intermittency of about 10 days was remarkable in the variation of the amplitude of the internal tidal waves.

In coastal sea areas, there are reports on the propagations of semidiurnal internal waves and their breaking at the shelf break in the northwestern coastal sea area of Australia (HOLLOWAY, 1984, 1985). The intermittency of about 10 days was noticeable in his records of water temperature and velocity components, though he describes nothing about it. In Japan, the reports of the internal tidal waves have increased in recent years; there are only two reports indicating the intermittency of the internal tidal waves for the present. INABA (1981) reported that in the subsurface layer of Suruga Bay, a diurnal period was dominant in the tidal current in contrast to the predominance of a semidiurnal period in the sea surface tide and this was due to the existence of an internal wave in the subsurface layer. MATSUYAMA (1987) suggested the intermittency of 7-10 days in the records of the velocity components in INABA (1981). In Uchiura Bay located at the head of Suruga Bay, the record of sea water temperature in the subsurface layer showed a predominant semidiurnal fluctuation, and this was due to resonance of the semidiurnal tide with the internal seiche in Uchiura Bay (MATSUYAMA, 1985). In addition, he de-

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scribed that the semidiurnal fluctuations intermittently disappeared in 3-5 days due to the passing of a typhoon near Suruga Bay. In the coastal sea of Joban, southern neighbour of the Sanriku sea area, the internal tidal waves were dominant in semidiurnal period and propagated onshore, and the intermittent behavior of the semidiurnal internal tide was noticeable in his record of the subsurface water temperature (MATSUNO, 1989).

Sanriku coast is one of the suitable fields for studying the phenomena of the internal mode, since the Tsugaru Warm Water (TWW) is lighter than the Oyashio Cold Water (OCW) (in spite of higher salinity, smaller water density than that of OCW is attributed to higher temperature of TWW), the strong thermocline is usually kept offshore. The lighter and warmer water flowing through the Tsugaru Strait to the Pacific Ocean from the Japan Sea is the origin of TWW, which is generally flowing southwards along Sanriku coast in a surface layer with thickness of 150-200 m (HANAWA, 1984). In autumn, TWW spreads sometimes about 100km to the east of the Tsugaru Strait before flows southward along the Sanriku coast. A remarkable pycnocline front (or thermocline front) at the sea surface is observed at the eastern boundary of TWW, because the heavier OCW is found under and off TWW. The depth of the thermocline under TWW becomes deeper shoreward as an extension of the surface front in contrast with the Kuroshio front which is shallower shoreward in the south sea area of Honshu. Thus, the thermocline is also clear near the coast, and the internal wave is easy to generate in such a sea area.

A phenomenon of "Sakashio", named by Japanese fishermen, occurs sometimes in many bays of the Sanriku coast. "Sakashio" means the subsurface tidal flow opposite to the surface flow. When "Sakashio" occurs in a bay, it is difficult to wind up "the Set Net", which is a kind of fish net widely used in Sanriku coast. This phenomenon is closely related to the occurrence of the internal waves in the bay. Therefore the internal waves are one of the important oceanographic phenomena for coastal fishery, and they are also important for cultural fishery, since the internal tidal waves force the exchange of coastal sea waters in the bay for offshore sea waters.

In order to clarify the behavior of the internal tidal waves in Sanriku coastal seas, the observations were carried out in one of the bays in Sanriku coast (Toni Bay, located in Kamaishi) from October to December 1984.

In this paper, several properties of the internal tidal waves become clear, especially their intermittent appearance in the bay. In chapter 2, the outline of observations will be given. In chapter 3, some typical examples of records are shown, and the properties of the internal tidal waves observed in Toni Bay and the intermittency in the internal tidal waves with duration of several days are explained. In addition, the intermittent property is described with relation to the vertical displacement of the thermocline. In section 1 of chapter 4, some evidence for the existence of the internal long period wave will be shown. Discussion is extended to the role of such waves as a cause of the intermittent vertical displacement of the thermocline and the relation between such waves and the oceanic front. In section 2 of chapter 4, the properties for propagation of the internal tidal waves in the bay will be stated in relation to the properties of the offshore internal tidal waves, and the shoaling up of the internal tidal waves into the bay will be discussed concerning the nature of the exchange of sea water in the coastal seas.

2. Observations and data

The Sanriku coast is called a Rias type in geology, and has a complicated coast line. The configuration of sea bottom in this sea area is also complicated in areas shallower than 130 m depth, and the bottom contours run almost straight north to south in deeper seas. The sea floor increases gradually in depth toward the Japan Trench. The complicated coast line is conspicuous, especially southward of Miyako Bay in the Sanriku coast. Otsuchi Bay is 33km southward, Kamaishi Bay is 45km southward of Miyako

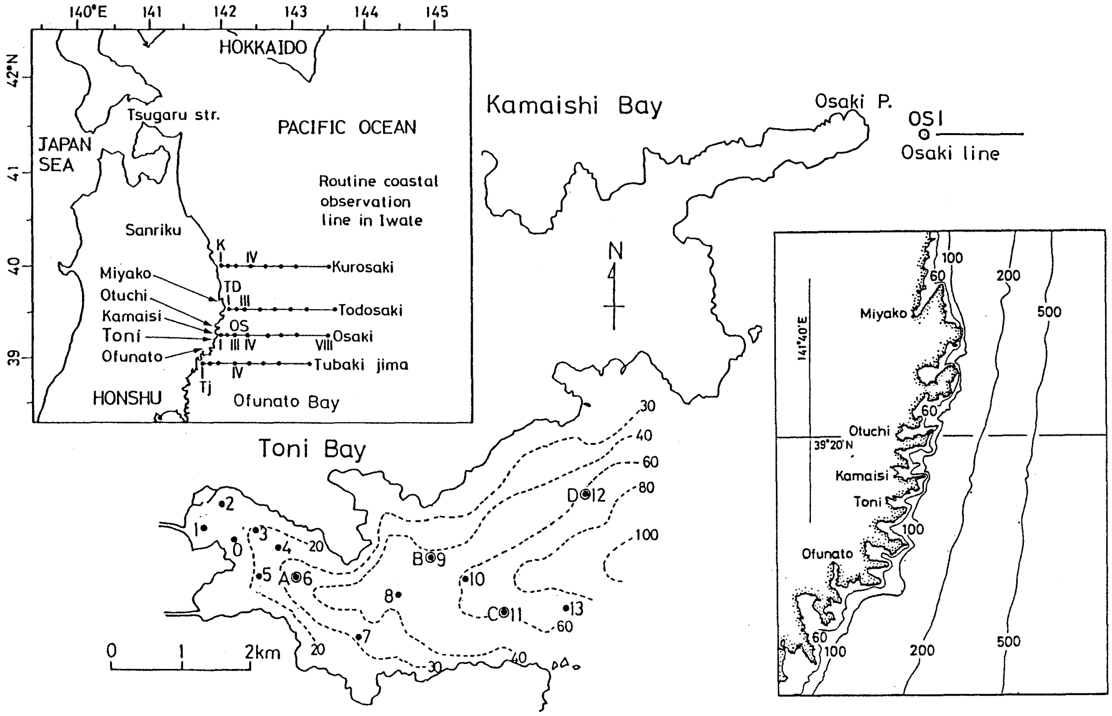


Fig. 1. Maps of Toni Bay and the adjacent sea area off Sanriku. A–D, mooring stations of Aanderaa current meters. 0–13, stations of STD-observation ; Stations A to D correspond to Stations 6, 9, 11 and 12, respectively.

Bay, and Ofunato Bay is 35km southward of Kamaishi Bay. Toni Bay is 8km southward of Kamaishi Bay (Fig. 1). Its bay mouth faces eastwards to the Pacific Ocean. The sea valley runs into the center of Toni Bay, and the breadth of the bay mouth is about 4km. The depth is about 90 m at the center of the bay mouth and about 40 m on the average; the length of the bay is 5–6 km.

Previous physical oceanographic research in Toni Bay showed that there was a counter-clockwise circulation in the bay and the flow in the bottom layer differed from that in the surface layer (TSUJITA, 1974).

Two observations were carried out in Toni Bay from 1 October to 15 December 1984. The first observation was made at 14 stations in Toni Bay (Sta.0 - Sta.13) every three days on a ship-contained STD (portable) which measured water temperature and salinity at 1 m intervals from the sea surface to the bottom (or maximum 80 m deep) (Fig. 1). The second observation was the continual observation by means of current meters which were fixed to the bottom by anchors and subsurface buoys of the mooring system. Sta.A (33 m depth) was settled near the head of the bay, Sta.D (65 m depth) was north of the center of the bay mouth, Sta.C (63 m depth) was south of the center of the bay mouth and Sta.B (44 m depth) was at the midpoint of the north side of the bay (Fig. 1). At all stations, Aanderaa current meters were set in the surface layer (10 m below sea surface) and in the bottom layer (5 m above bottom) to measure current speed, current direction, water temperature and salinity every 10 minutes. The record of a current meter was averaged over an hour before analysis. The continual record was divided into two parts, 1 October - 8 November and 9 November - 15 December. Unfortunately, the record of the current meter in the bottom layer at Sta.D was not obtained because of

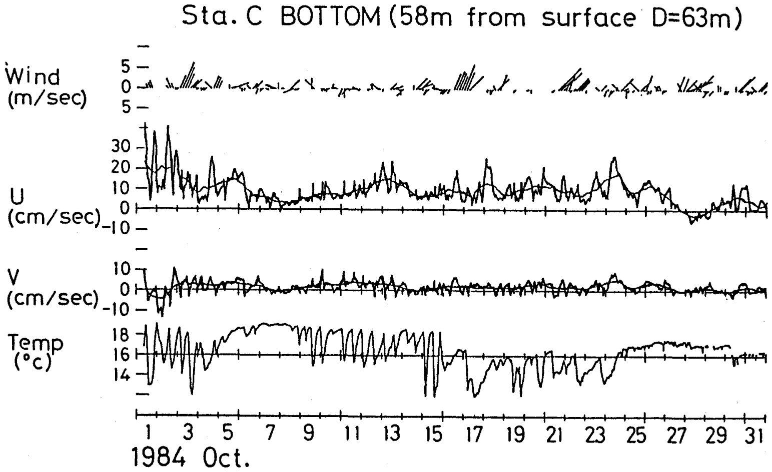


Fig. 2. An example of the time series of Aanderaa current meter record in the bottom layer at Sta. C (Oct. 1-31, 1984). Wind, vector expression of wind every 3 hours. U, eastward component of velocity (thick line) and its 25 hour running mean (thin line). V, northward component of velocity (thick line) and its 25 hour running mean (thin line). Temp., sea water temperature.

mechanical trouble.

In addition to those records, the following data of the routine observations by governmental offices were available to the present paper:

1) The monthly data of routine coastal observations in 4 lines off the Sanriku coast by Iwate Prefecture Fishery Experimental Station (Fig. 1).

2) The hourly data of tidal observations in Miyako Bay, Kamaishi Bay and Ofunato Bay (the forecasted data and the observed data) by Branches of Meteorological Agency and others.

3) The meteorological data every three hours at Miyako, Kamaishi and Ofunato (air pressure, wind speed and wind direction).

4) Simultaneous data of temporal deep sea observations far off Sanriku, by Meteorological Agency.

The Iwate Prefecture Fishery Experimental Station has carried on the monthly observation of water temperature and salinity in several depths shallower than 300 m at each station in 4 observation lines off the Sanriku coast. In each observation line, 8 stations are set, for example, Sta.1 is 0.7 km and Sta. 8 is about 130 km from the coast in the Osaki line. Details of 4 coastal routine observation lines are:

Kurosaki Line (K I - KVIII) (40°00'N, 141°52'−143°30'E);

Todosaki Line (TD I - TD VIII) (39°32'N, 142°06'−143°35'E);

Osaki Line (OS I - OSVIII) (39°15'N, 142°04'−143°30'E);

Tsubakijima Line (TJ I - TJVIII) (38°56'N, 141°44'−143°14'E).

Those routine data were very useful to the present work as indicators of information in the offshore sea area, especially the Osaki line located about 3 km from Toni Bay (Fig. 1).

3. Analysis and results

1) An example of records

a) Time series of current meter records

Time series of several components of the current meter record in the bottom layer at Sta.C are shown in Fig. 2. The variation of water temperature is apparently different from that in the surface layer (refer to Fig. 6). Water temperature fluctuated periodically and its range was 6℃ in maximum value. Before 15 October, the period of the fluctuations was semidiurnal, but it was near-

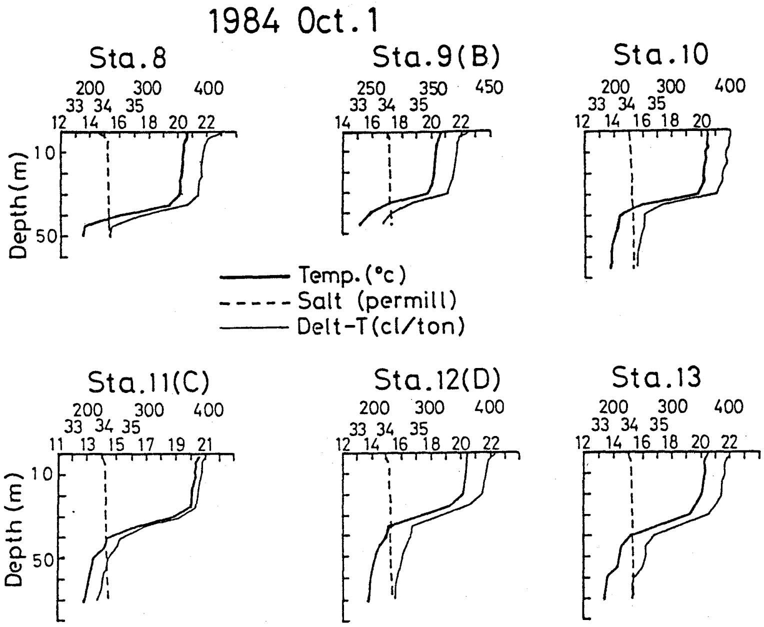


Fig. 3. Vertical distribution of temperature (℃), salinity (permill) and specific volum anomaly (cl/ton) of sea water in the mouth of Toni Bay (14:43 - 15:46, Oct. 1, 1984).

ly diurnal in 16-24 October, though its fluctuation was considerably disturbed. It is of interest that the days of steady and high temperature were 5-8 and 25-29 October. After 29 October, the record is obscure because of some loss of record from troubles with the water temperature sensor. On the other hand, in the surface layer, water temperature tends to decrease gradually, and sometimes drops 1-2℃ per day (Fig. 6). This change corresponded to the duration of fluctuation of water temperature in the bottom layer, which suggested that the dominant fluctuation of bottom water temperature was relivant to the lowering of surface water temperature.

The eastward component of velocity (U) in the bottom layer mostly fluctuated in the positive area, which meant that the flow was generally eastward (Fig. 2). The basic flow in the bottom layer at Sta.C was eastward and it seemed to be related to counterclockwise circulation in Toni Bay (TSUJITA, 1974). The magnitude of fluctuation of the U or V component in the surface layer was equal to that in the bottom layer (figure of the record in the surface layer at Sta.C is not shown). U and V fluctuated periodically, but they were rather disturbed by noise compared with the fluctuation of water temperature. The fluctuation of semidiurnal period prevailed in the beginning of October and the fluctuation of diurnal period was found with that of semidiurnal period in the second half of October. When the tidal fluctuation of bottom water temperature was large, fluctuation of U reached to 40 cm/sec in range of U (in the term of about 6 hours).

The vector expression of wind was composed of records of wind speed and direction every 3 hours at Kamaishi. During the observations, the wind blew weaker than the usual condition in late autumn. For example, the wind speed was usually 3-4 m/sec and sometimes 7-8 m/sec.

b) Data of STD measurement

Fig. 3 is an example of the vertical distribution of water temperature, salinity and specific volume anomaly at six stations near the bay mouth from STD measurements during the afternoon on 1 October. A very clear thermocline was found at a depth of 30-40 m

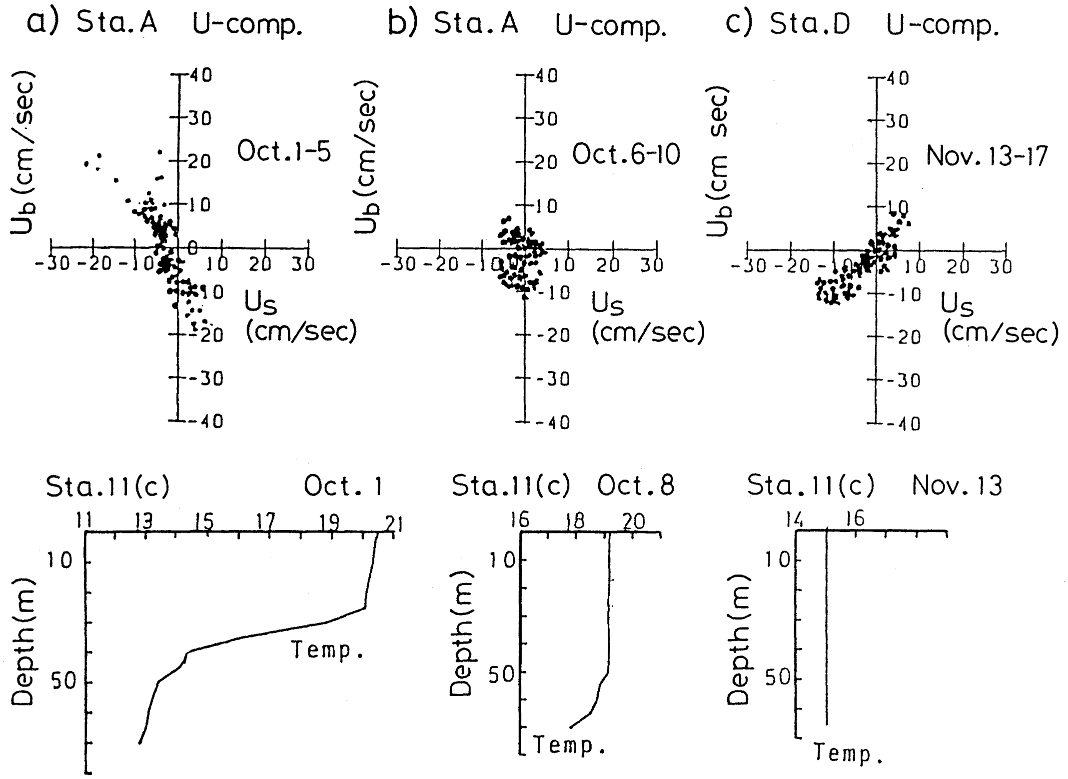


Fig. 4. Correlations between velocity components in the surface and in the bottom layers, and vertical distributions of sea water temperature. X-axis, Us (velocity component in the surface layer); Y-axis, Ub (velocity component in the bottom layer). a) strong density stratification (Oct. 1-5, 1984); b) transient density stratification (Oct. 6-10, 1984); c) vertically homogeneous density (Nov. 13-17, 1984).

in Toni Bay. The thickness of the thermocline was about 10 m and the temperature difference between upper and lower layers was 6℃ (20-14℃) in maximum value. On the other hand, salinity was almost homogeneous (Sal.> 34.0 permill) at all depths in Toni Bay, hence, colder sea water in the bottom layer of Toni Bay was not the Oyashio Water (Sal.< 33.8 permill) but the cooled Tsugaru Warm Water.

The strong density stratification in Toni Bay depended on the vertical distribution of water temperature.

2) Properties of the internal tidal waves

Vertical distribution of specific volume anomaly of sea water and currents in stratified sea

The thermocline of about 10 m thickness between the upper warmer sea waters about 20℃ and the lower colder sea waters less than 14℃ has a very large vertical gradient of water temperature (0.6℃/m, Fig. 3). When stratification occurs in Toni Bay, an inverse correlation between the velocity components in the surface and the bottom layers is shown at top of Fig. 4a. This correlation of currents between both layers indicates a dominant internal mode.

On the other hand, the density distribution in the bay was homogeneous on 13 November at the bottom of Fig. 4c. The vertical distribution of currents was also homogeneous in 13-17 November (top of Fig. 4c).

The density stratification was weak on 8 October, and the correlation between the velocity components in the surface and the bottom layers seemed to be zero (Fig. 4b). This shows that the vertical distribution of currents in the bay was in a transient state between the strong density stratification state (Fig. 4a) and the homogeneous distribution state (Fig. 4c).

Spectral property of fluctuations

As the fluctuation of bottom temperature was different between the terms of 1-4 and 16-24 October (Fig. 2), power spectra of water temperature in the bottom layer at Sta.C were calculated for each of the terms (Fig. 5a). Power spectra of water temperature for the former had predominant period of 13 hours, which nearly equaled the semidiurnal period (left of Fig. 5a). Power spectra in the bottom layer at Sta.A and Sta.B had a prevailing semidiurnal period in this term.

On the other hand, for 16-24 October, the predominant period was about 35 hours in the bottom layer at Sta.B and Sta.C (right of Fig. 5a), and there was no dominant period in density distribution of power spectra at Sta. A in the bay head (refer to Fig. 6).

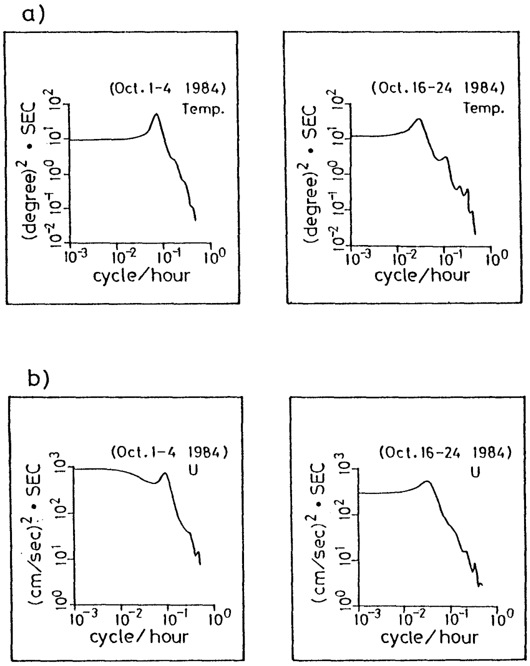


Fig. 5. Power spectra for variations of sea water temperature and for the eastward component of velocity at Sta. C bottom. a) Temperature; dominant periods are 13 hours (Oct. 1-4, 1984) and 35 hours (Oct. 16-24, 1984). b) Velocity; dominant periods are 11 hours (Oct. 1-4, 1984) and 31 hours (Oct. 16-24, 1984).

Comparing eastward components of velocity (U) for 1-4 October with those for 16-24 October at Sta.C (Fig. 2), the amplitude of fluctuation in the former was larger than that in the latter, and those seemed to have a similar period. The power spectral density of U for 1-4 October had a dominant period at about 11 hours near the semidiurnal period (left of Fig. 5b). The density of low frequency was large; this was shown in a gradient of the smoothed curve (running mean velocity) in the fluctuation of U in Fig. 2. In the bottom and surface at Sta.A and Sta.B, and in the surface at Sta.D, the predominant period of the semidiurnal was obtained, but it was about 14 hours in the surface at Sta.C.

For 16-24 October, the power spectra of U had a dominant period of about 31 hours, similar to the case of water temperature (right of Fig. 5b), and in the bottom at Sta.A and Sta.B the dominant periods were about 22 and 19 hours, respectively.

As mentioned above, there was apparently a difference of period between the two terms in both water temperature and velocity component (U).

The characteristics in fluctuation of water temperature in Toni Bay

In Fig. 6, water temperature in the surface layer varies similar to an envelope of water temperature in the bottom layer at each station. The patterns of bottom water temperature at the three stations are similar to each other, and their fluctuations seem to decrease gradually from Sta.C at the bay mouth to Sta.A at the bay head. The other noticeable feature of the fluctuation of water temperature in the bottom layer is that there are several calm days or the days of no periodicity. The internal tidal waves seem to be strongly intermittent (Fig. 6). It should be noted that for 8-15 October, the maximum of water temperature at the bottom layer at Sta.C was nearly equal to that at the surface throughout the term. This suggests that the

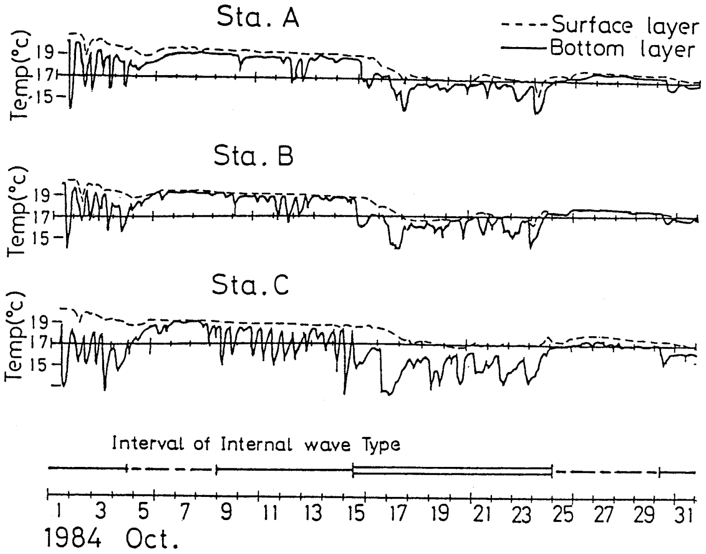


Fig. 6. Comparison of sea water temperature variations in the surface with those in the bottom layer at Stations A, B and C. At the bottom of the figure, the term of the internal wave type is shown: single line, the term of the semidiurnal fluctuation of sea water temperature at Sta. C in Fig. 2; double line, the term of diurnal fluctation; chain line, the term of stable and high temperature (no fluctuation).

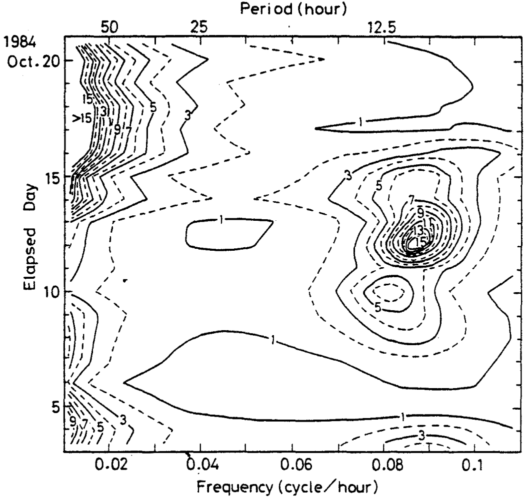
thermocline disappeared in the bay; the thermocline sank deeper than the depth at the bay mouth and the warm surface water filled the whole depth in the bay. The colder sea water at the bay bottom repeated to flow in and to flow out every tidal period for 8-15 October. This is an interesting mechanism for the exchange of sea water in a shallow bay.

3) Intermittency of the internal tidal waves and vertical displacement of pycnocline

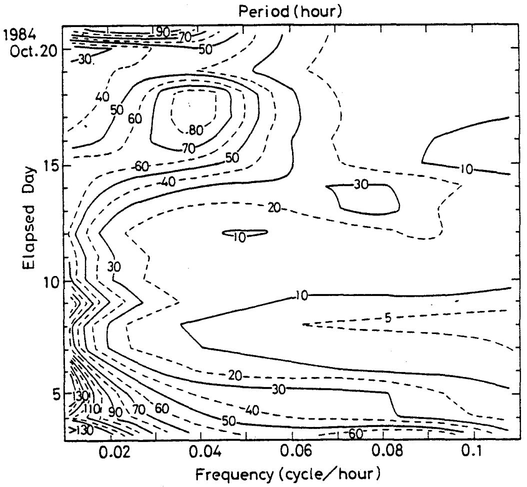
a) Intermittency of the internal tidal waves

The pattern of fluctuations of water temperature in Fig. 2 suggests the intermittency of the internal tidal waves. In the record of water temperature, semidiurnal internal tidal waves were predominant for 1-4 and 9-15 October, near diurnal were dominant for 16-24 October, and the terms of the stable and higher water temperature were for 5-8 and 25-29 October. In fluctuations of velocity component (U), amplitudes of U seemed to be diminished in the terms of stable and higher water temperature and this was due to the intermittency of the internal tidal waves in the bay.

To confirm the intermittency, "the figures of the day by day variations of density of power spectra" from records in the bottom layer at Sta.C are shown in Fig. 7. The figure has frequency of fluctuations on the X-axis and the elapsed days of 3-21 October are marked on the Y-axis. Isosteric lines of the power spectra of fluctuation are shown in the figure. Power spectra of fluctuations were calculated at terms of every 5 days from 1 to 23 October. For example, the power spectra of 3 October at bottom in the figure were calculated on data in 1-5 October, next power spectra of 4 October were calculated from data in 2-6 October. Those calculations were carried out to 21 for data in 19-23 October day by day. The dominant periods for fluctuations of water temperature are at 11 hours near the semidiurnal period and at long period component (above 50 hours) on 4 October (the representative day of 2-6 October, Fig. 7a). The density of power spectra decreases to lower levels at all frequency fields in 5-8 October. The semidiurnal period component increases in 10-14 October. After 15 October, the components of frequency shorter than 25 hours disappear and those of frequency longer than 25 hours



a) Temp. Sta. C bottom layer



b) Velocity (U) Sta. C bottom layer

Fig. 7. Day by day variations of power spectra at Sta. C bottom layer. Power spectra were calculated every 5 days sliding a day (Oct. 1-23, 1984). a) Sea water temperature (Temp.). b) Eastward component of velocity (U).

become more dominant.

Another figure of day by day variation in density of power spectra is shown in the eastward component of velocity (U, Fig. 7b) in a similar manner to water temperature. Distributions of isosteric lines differ from those of water temperature, and the peaks at each frequency in each elapsed day are more obscure than those of water temperature. The components of near semidiurnal period and long period (above 50 hours) are dominant for the first 5 days, and the components at all frequencies are at lower levels for 7-13 October. The predominant component is a semidiurnal period for 13-14 October and a diurnal period is prevailing for 16-18 October.

To conclude, the figures were very suggestive of the intermittency of the internal tidal waves in the bay.

b) Vertical displacement of pycnocline (thermocline)

The inflowing of colder sea water to the bottom of Toni Bay from offshore was confirmed from the result that the lowering of water temperature generally took place earlier at Sta. C than at Sta. A (for example, Fig. 17).

Next problems were where the origin of colder waters offshore was and how deep the layer of colder waters was. In order to solve those problems, T-S diagram analyses of sea waters for the term of density stratification were made (Fig. 8). The waters in the hatched area (13-15℃, about 34.2 permill) in Fig. 8a were the bottom water in the bay, the waters in area enclosed with broken lines (19-21℃, 33.9-34.2 permill) were the surface water. The waters of similar property to the bottom waters in the bay were found in 70-100 m layer at nearshore stations in three lines north of the Osaki line (Fig. 8b, c, d). An offshore thermocline of 13-17℃ (near Sta. OSV) was found at 40 m depth, increased in depth towards the coast, and was found at 75-100 m depth at Sta. OS II (8 km off coast, Fig. 14c). This deepening of the thermocline near the coast is usual in the vertical distribution of water temperature in this season. The bottom sea water in the bay was different from the offshore sea water at the correspondent depth; therefore, it might be the offshore sea water rising up from a slightly deeper thermocline by an unknown external force. When the thermocline nearshore rose intermittently the density stratification appeared in Toni Bay and the internal tidal waves propagated into the bay.

The sea waters similar in T-S property to

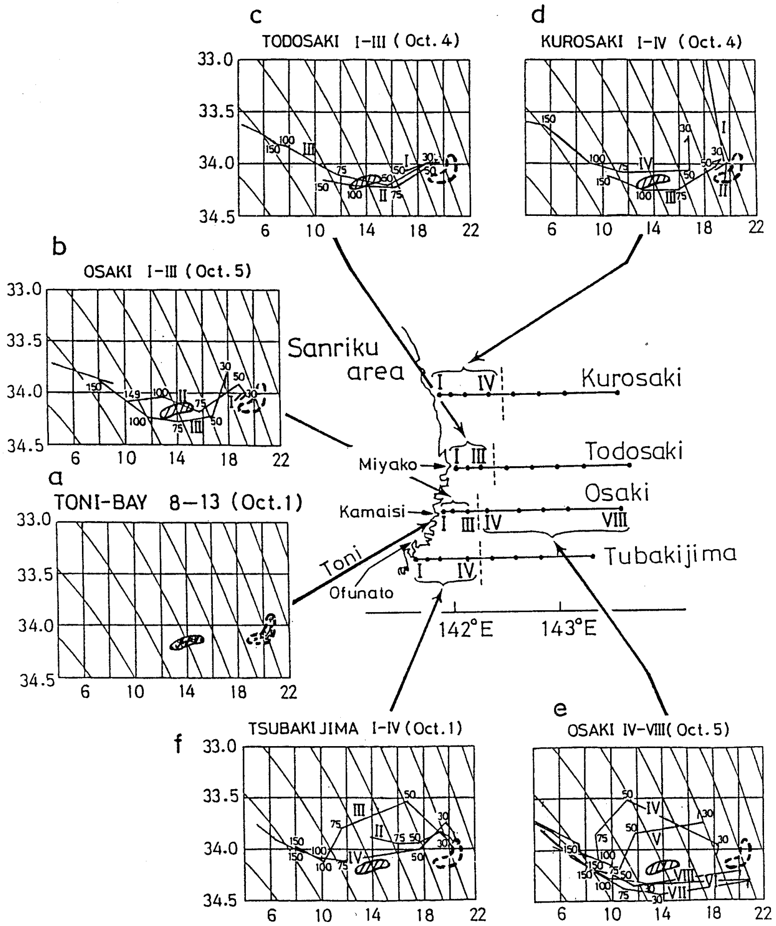


Fig. 8. Comparisons of the sea water property in T-S diagram in Toni Bay with that in the offshore sea area. Hatched area in T-S diagram: T-S property of the colder sea water at the bottom in Toni Bay. Area bounded by broken line in T-S diagram: T-S property of the warmer sea water at the surface in Toni Bay. I, II, III⋯⋯: number of the offshore station. 10, 50, 75⋯: observed depth (m). a) T-S diagram of Stations 8-13 in Toni Bay. b) T-S diagram of Stations I-III in Osaki line. c) T-S diagram of Stations I-III in Todosaki line. d) T-S diagram of Stations I-IV in Kurosaki line. e) T-S diagram of Stations IV-VIII in Osaki line. f) T-S diagram of Stations I-IV in Tsubakijima line.

the bottom sea water in the bay were not found at stations offshore from Sta. OSV and at all southern stations in the Tsubakijima line (Fig. 8e, f). Therefore, the intermittent vertical displacement of the thermocline occurred only in the northern sea area of Toni Bay.

It is confirmed from observations that the intermittency of the internal tidal waves in Toni Bay was due to the vertical displacement of the thermocline on a time scale of several days. Remarkable meteorological disturbances were not found in the term under investigation since wind was usually weaker than 5 m/sec in October 1984 (Fig. 2). Therefore, the long period waves were of interest for the cause of vertical displacement of the thermocline on a time scale of several days, if those waves existed in the Sanriku coastal seas.

4. Discussions and conclusions

1) Some evidence on the internal long period waves

In chapter 3, it was pointed out that the internal tidal waves appeared intermittently in the time scale of several days, and the T-S property of colder sea waters in Toni Bay coincided with colder sea waters under the thermocline in a slightly deeper layer outside of Toni Bay.

It is only recently that the intermittency in the internal tidal waves attracted scientist's attention (e.g. WUNSCH, 1975). However, there are very few reports on this problem. In Japan, a few researchers have noticed such an intermittency in the continual records of sea water temperature and current velocity in the subsurface layer. They concluded that this resulted from the disappearance of stratification of the ocean caused by a change in the wind system, e.g. access of a typhoon (INABA, 1981; MATSUYAMA, 1985). The intermittent variations were clearly found in the record of bottom water temperature in the Joban coastal sea area, southern neighbour of the Sanriku sea area, though he described nothing about it (MATSUNO, 1989). Similar intermittent variation was found in the record of bottom water temperature and current velocity components in subsurface layers in the northwestern coastal sea of Australia (HOLLOWAY, 1985). Thus the intermittency in the internal mode occurred generally in every sea area in the world, though its origin and structure were different in each sea area.

In the Sanriku coastal seas, it was possible that the space scale of the intermittency of the internal tidal waves had a larger horizontal scale than that of Toni Bay (Fig. 8). Similar variations of temperature were expected in the bay adjacent to Toni Bay. It was very convenient that a continuous measurement of sea water temperature had been carried out in several subsurface layers above 15 m deep at Otsuchi Bay to the north of Toni Bay (Fig. 1, SHIKAMA *et al.*, 1985). A variation of sea water temperature (1 hour running mean values of every 10 minutes records) at 10 m depth in Otsuchi Bay (observing station was located at about 6 km inward from the bay mouth) was very similar to that in the surface layer at Sta.D in Toni Bay (Sta.D was located at about 1 km inward from the bay mouth). The records in Fig. 9 are the subsurface water temperature deviations of 25 hours running mean values from mean value of full data in Toni Bay and Otsuchi Bay. A temporal decrease of water temperature appeared in Otsuchi Bay on 3 and 17 October, and a similar temporal decrease appeared in Toni Bay a day later. Those variations of water temperature in the two bays were in high correlation with each other and the cross correlation coefficient (α) was 0.89. The propagating speed of this decrease was estimated from the difference of the propagating distances for the two stations in the bays and the lag (22 hours) of the time when α was maximum in the cross correlation. Therefore, it corresponded to the length of 15 km (=20 - 6 + 1), and the propagation speed of a long period wave was estimated about 19 cm/sec and from north to south in direction.

This propagating speed was compared with the phase speed of the coastal trapped wave (internal Kelvin type wave) calculated from observed data. The dispersion relation of the coastal trapped wave was calculated by means of a reduced gravity model taking into account the details of bottom configuration. The estimated phase speed of the coastal trapped wave was more than 30 cm/sec; this was considerably larger than the propagating speed of the above long period wave (19 cm/

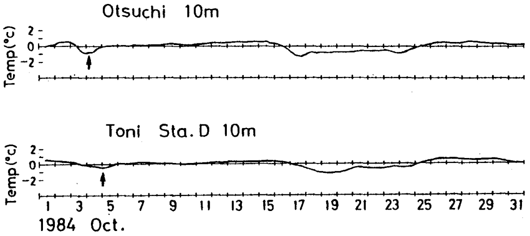


Fig. 9. Comparison of sea water temperature variation in Toni Bay with that in Otsuchi Bay (Oct. 1-31, 1984). Deviations of 25 hour running mean value from the mean value of full data. Arrows: the moment of temporal decrease of sea water temperature.

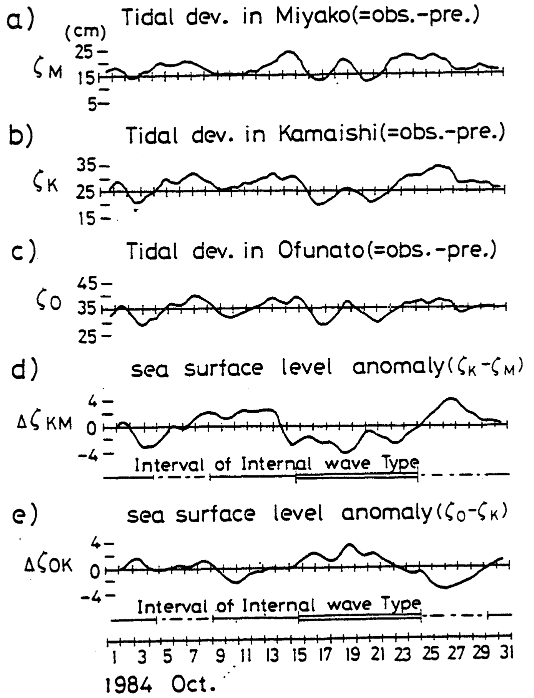


Fig. 10. Comparison of sea surface levels in three bays (cm). Terms of internal wave type in d) and e) are the same as those in Fig. 6. a) ζ_M is value of 25 hour running mean of the tidal deviation in Miyako Bay. b) The same as in a) except for in Kamaishi Bay. c) The same as in a) except for in Ofunato Bay. d) $\Delta\zeta_{KM}$ is the sea surface level anomaly (local difference of tidal deviations) between Kamaishi Bay and Miyako Bay ($\Delta\zeta_{KM} = \zeta_K - \zeta_M$). e) The same as in d) except for between Ofunato and Kamaishi Bays ($\Delta\zeta_{OK} = \zeta_O - \zeta_K$).

sec). The small magnitude of the phase speed suggested that the long period wave was a kind of internal wave; the internal long period wave treated here was different from the coastal trapped wave.

In the coastal seas of Japan, some results on the long waves were reported. In the Joban coastal sea area (southward of the Sanriku coast), the periodical current fluctuation (about 100 hours) was dominant and it propagated southward with speed of 3-5 km/hour (83-139 cm/sec), and this corresponded to the second mode and the third mode of the shelf waves (KUBOTA *et al.*, 1981; KUBOTA, 1982, 1985). These reports were related to the external long wave, and the propagation speed was larger than that of the internal long period wave in the present study.

On the other hand, there are few reports in Japan on observations of the internal long period wave as yet. When the internal long period waves propagate from north to south along the coast, it is expected that the sea surface level changes out of phase to the depth of the thermocline, even if it is very small. The deviations of the observed tide (after correction by atmospheric pressure) from the predicted tide were obtained in each of Miyako Bay, Kamaishi Bay and Ofunato Bay (Fig. 10a, b, c). These sea surface level anomalies are shown in Fig. 10d, e. Although $\Delta\zeta_{KM}$ contains some noise, $\Delta\zeta_{KM}$ is evidently negative with its magnitude of 3-4 cm for 1-5 October and 14-24 October when the internal tidal waves were dominant in Toni Bay (except 9-13 October). The negative $\Delta\zeta_{KM}$ means that sea surface level at Kamaishi Bay was lower than that at Miyako Bay. Because the sea surface level variation caused by the internal wave changes out of phase with that of the thermocline as mentioned above, the negative sea surface level anomaly ($-\Delta\zeta_{KM}$) in Fig. 10d probably indicates upward displacement of the thermocline at Kamaishi, and the dominant fluctuation of the thermocline may appear in the shallow bay in those terms (Fig. 10d and Fig. 6). The time variation of $\Delta\zeta_{OK}$ (Fig. 10e) is out of phase with that of $\Delta\zeta_{KM}$ and the amplitude of $\Delta\zeta_{OK}$ seems to be a little smaller than that of $\Delta\zeta_{KM}$. $\Delta\zeta_{KM}$ is inversely proportional to $\Delta\zeta_{OK}$ (Fig. 11), and the variation of sea surface level near Miyako Bay was in phase with that near Ofunato Bay. Therefore, the tendencies of $\Delta\zeta_{KM}$ and $\Delta\zeta_{OK}$ indicated the existence of the internal long period wave along the Sanriku coast.

Those results suggested the existence of internal long period waves propagating alongshore with an appropriate space scale (about 100 km) that was nearly twice the distance between Miyako Bay and Kamaishi Bay

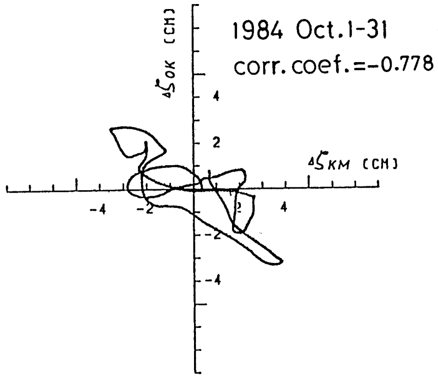


Fig. 11. Correlation between the sea surface level anomalies, $\Delta\zeta_{KM}$ and $\Delta\zeta_{OK}$ (cm) (Oct. 1-31, 1984).

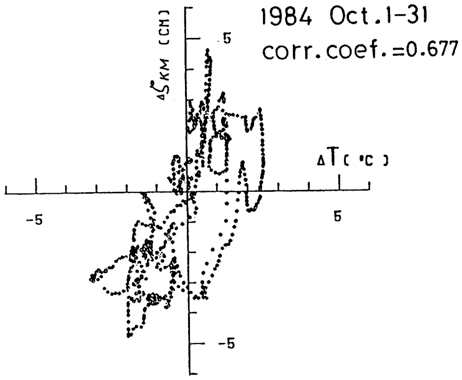


Fig. 12. Correlation between the deviation of sea water temperature (ΔT, ℃) at Sta. C bottom and the sea surface level anomaly ($\Delta\zeta_{KM}$, cm) (Oct. 1-31, 1984).

(about 45 km). The tendency that the amplitude of $\Delta\zeta_{OK}$ was a little smaller than that of $\Delta\zeta_{KM}$ was speculated to occur because the distance between Ofunato Bay and Kamaishi Bay was about 35km which was fairly shorter than a half of the space scale of the internal long period waves. Also, the amplitude of $\Delta\zeta_{KM}$ (3-4 cm) in Fig. 10d was a reasonable order in relation to the magnitude in the density difference of sea water ($\Delta\rho = 0.0011$-0.0017) in the surface and bottom layers, compared with the vertical displacement of the thermocline (H_L: about 20m, estimated later) caused by propagation of the internal long period waves ($\Delta\zeta_{KM}/H_L = \Delta\rho/\rho$, $\Delta\zeta_{KM} = 0.0017 \times 20\text{m} = 3.4\text{cm}$).

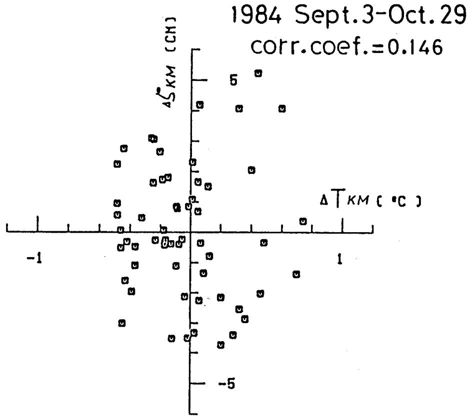


Fig. 13. Correlation between the sea surface level anomaly ($\Delta\zeta_{KM}$) and the local difference of sea surface water temperature (ΔT_{KM}, Kamaishi and Miyako, data is one a day) (Sept. 3-Oct. 29, 1984).

Next, the relation of the time changes in $\Delta\zeta_{KM}$ (or $\Delta\zeta_{OK}$) and in the vertical displacement of the thermocline will be examined. Unfortunately, there was no continual record of the vertical displacement of the thermocline during this observation. Hence, the record of sea water temperature (after 25 hours running mean) in the bottom layer at Sta.C in Toni Bay was treated instead of the vertical displacement of the thermocline. When the thermocline becomes shallower (deeper), the deviation of sea water temperature in the bottom (ΔT, ℃) will decrease (increase). The correlation between $\Delta\zeta_{KM}$ and ΔT was positive and the correlation coefficient (α) was 0.68 (Fig. 12). This meant that negative $\Delta\zeta_{KM}$ corresponded to the lower sea surface level near Kamaishi than that near Miyako, and the lower sea surface level corresponded to a shallower thermocline near Kamaishi in the internal mode. Consequently, a shallower thermocline corresponded to the lower water temperature in the bottom layer of Toni Bay near Kamaishi. The positive correlation between $\Delta\zeta_{KM}$ and ΔT in Fig. 12 was very reasonable. These results suggested propagation of a wave from Miyako Bay to Ofunato Bay, and supported statistically the existence of the internal long period waves.

However, there was another possibility of high correlation between $\Delta\zeta_{KM}$ and the deviation of sea water temperature; the time change of $\Delta\zeta_{KM}$ was possible to depend on the variation of the local difference of sea surface water temperature between Kamaishi Bay and Miyako Bay (ΔT_{KM}, ℃). NISHI and KUNISHI (1985) investigated the influence of the local difference of sea water temperature in the surface layer upon the difference of sea levels in two distant stations off Shikoku Island. In the present study, there was no relationship between $\Delta\zeta_{KM}$ and ΔT_{KM} (the latter was only one observation each day, Fig. 13). Therefore, the variation of $\Delta\zeta_{KM}$ and $\Delta\zeta_{OK}$ was possibly due to the internal long period waves, and the existence of the internal long period waves was highly possible.

The space scale (about 100 km) was a match for the time scale (several days) of the internal long period waves. Thus, the space scale through the local difference of sea surface levels in the two bays also verified the propagation of the internal long period waves along the Sanriku coast.

As mentioned above, the intermittency of the internal tidal waves in Toni Bay was attributed to the propagation of the internal long period waves accompanied by the vertical displacement of the thermocline. The internal long period waves were independent of the internal tidal waves in their mechanism of generation and propagation. The superposition of these two kinds of waves created a

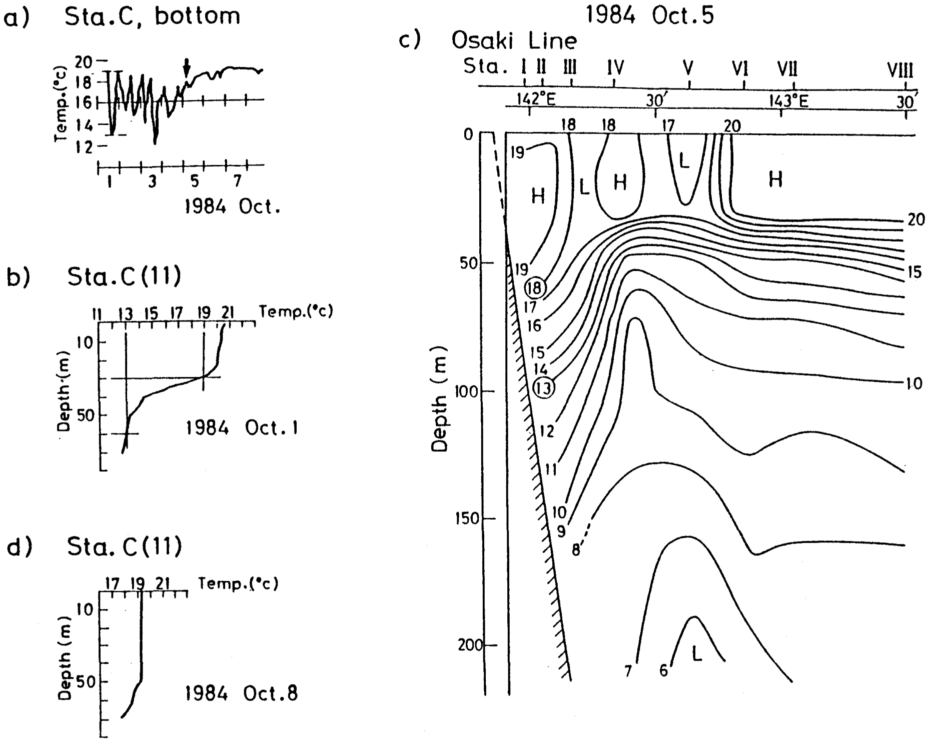


Fig. 14. Time series record and vertical distributions of sea water temperature. a) Time series record of the sea water temperature at Sta. C bottom (Oct. 1-7, 1984). Arrow corresponds to the observation time of vertical distribution of sea water in c). b) Vertical distribution of the sea water temperature at Sta. C (Oct. 1, 1984). c) Vertical distribution of the sea water temperature in Osaki line (Oct. 5, 1984). d) Vertical distribution of the sea water temperature at Sta. C (Oct. 8, 1984).

new phenomenon (the intermittency of the internal tidal waves) in the bay.

The wave heights of the internal tidal waves and the internal long period waves

From two kinds of records of water temperature in Fig. 14, wave heights of the internal tidal waves (H_T) and the internal long period waves (H_L) were estimated. From the continual record of the sea water temperature (Fig. 14a) in the bottom layer (58 m deep) at Sta.C, the sea water temperature fluctuated semidiurnally between 19 and 13℃ on 1 October. As the magnitude of the semidiurnal fluctuation is related to the height of the internal tidal wave (H_T), H_T can be estimated when the vertical distribution of the sea water temperature is simultaneously obtained. Fig. 14b is the vertical distribution of the sea water temperature at Sta.C in the afternoon on 1 October and shows a very conspicuous thermocline in the bay. The isotherm of 19℃ was 30 m deep and that of 13℃ was 60 m deep, and the difference of these depths was about 30 m. From (a) and (b) of Fig. 14, the wave height of the internal tidal wave (H_T) was estimated to be about 30 m (on 1 October).

On the other hand, the continual record of sea water temperature in Fig. 14a shows a fluctuationless period of water temperature higher than 18℃ at the bottom in several days after 5 October. This shows that the warmer sea water in surface layer extended all layers and the thermal stratification of sea water was weak in the bay (Fig. 14d). The thermocline existed in the bay on 1-4 October and then it sank deeper and disappeared in the bay on 5-8 October (Fig. 14a, d). The vertical distribution of offshore water temperature (in the Osaki line) was obtained in the morning of 5 October and the sea water of 18℃ was distributed from the sea surface to about 60 m deep (Fig. 14c), and the corresponding sea water temperature at 58 m deep (the bottom layer) in the bay was about 18℃ (indicated by the arrow in Fig. 14a). The sea water of 13℃ found at about 60 m deep in the bay on 1 October (Fig. 14a, b) descended about 40 m from 60 m deep to 100 m deep on 5 October (Fig. 14c). This vertical movement of the isotherm probably corresponded to the vertical displacement of the thermocline by the superposition of the internal tidal wave (H_T) and the internal long period wave (H_L). Therefore, the wave height of the internal long period wave (H_L) of about 10 m was obtained as the difference of 40 m ($H_T + H_L$) and 30m (H_T). In addition, the sea water temperature of 18℃ in the morning of 5 October was not the maximum temperature of the sea water yet, but the maximum temperature (about 19℃) was found on 7-8 October (Fig. 14a). This meant that, for example, the maximum depth of the isotherms on 7 October in phase with the deepest thermocline might be found about 10 m deeper than that on 5 October (Fig. 14a, c). Accordingly, the vertical displacement of waves ($H_L + H_T$) of about 50 m corresponded to the height of the internal long period wave (H_L) of about 20 m. Ultimately, the height of the internal long period wave in the beginning of October 1984 was estimated about 20 m in the Sanriku coastal seas.

The internal long period waves and the behavior of offshore front at sea surface

Considering the characteristic ocean structures off Sanriku containing the Tsugaru Warm Current (coastal boundary current), the internal long period waves are very possibly the internal coastal boundary wave.

In some satellite images, there is often a solitary wavelike behavior of a clear front at the sea surface between the Tsugaru Warm Water (TWW) and the Oyashio Cold Water (OCW) off the Sanriku coast. In autumn 1984, TWW spread over the eastern sea area of the Tsugaru Strait. For example, it was found in satellite picture images that the offshore convex-shaped front moved southward with a phase speed of about 16 cm/sec (Fig. 15, YASUDA *et al.*, 1987). This propagation speed of the offshore convex-shaped front was quite similar to the propagation speed (19 cm/sec) of the internal long period waves described above and this suggested some relationships between them. The offshore front between TWW and OCW extended the thermocline in the coastal sea area, and the thermocline became deeper approaching the coast (Fig. 14c). From this relation between them, the vertical displacement of the thermocline nearshore was possibly related to the offshore convex-shaped front.

There are many examples of the coastal boundary currents with the sea surface front and those flow generally along the coast on the right-hand side (in the northern hemisphere) in the world ocean. The wavelike behavior of those oceanic fronts is clearly seen in recent picture images of satellites.

Theoretical research on the wavelike behavior of oceanic fronts has been activated in the 1980's.

The semigeostrophic coastal current has two waves in a reduced gravity model in which a little lighter sea water (of uniform potential vorticity) in the upper layer flows along the coast as quasi-geostrophic current over a heavier sea water (of no flow) in the lower layer which has a thickness much larger than that of the upper layer (KUBOKAWA and HANAWA, 1984; KUBOKAWA, 1986). The first wave is a Semigeostrophic Coastal Wave (SCW, Kelvin wave type) and is characterized by the variation in the depth of the upper layer near the coast without change in the breadth of the current. The second wave is a Semigeostrophic Frontal Wave (SFW) characterized by the variation in the breadth of the current and propagates upstream. This was a very simple model neglecting the flow in the lower layer and the sea bottom configuration.

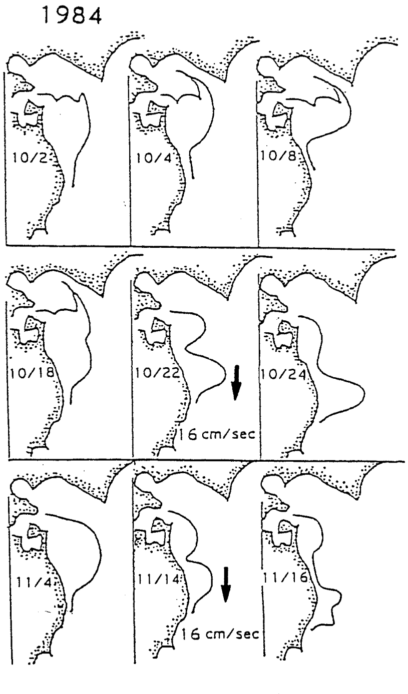


Fig. 15. Wavelike behavior of the sea surface front between the Tsugaru Warm Water and the Oyashio Cold Water from satellite images (by YASUDA *et al*., 1987). Arrow: the propagation of wavelike front.

Following these papers, KUBOKAWA (1987, 1988a, b) studied a two layer model with a finite depth of the lower layer, taking into account the effects of shallow depth nearshore and the flow in the lower layer. When there is a flow in the upper layer and the mean flow is zero in the lower layer, a pycnocline between the two layers inclines and a vorticity gradient arises in the lower layer, and the wave of vorticity mode appears in the lower layer. When the wave of vorticity mode in the lower layer couples with SFW in the upper layer, the baroclinic instability is generated and the disturbance of the density front propagates at the speed of the wave of vorticity mode in the lower layer. This disturbance of the front from the baroclinic instability exists when the basic current in the upper layer is weak near the coast or the breadth of the current is large. These conditions were satisfied in the Sanriku sea area in autumn 1984. Furthermore, KUBOKAWA showed that it was possible to grow for small amplitudes of the initial disturbance of the front by coupling the waves of two types in the upper and lower layers as mentioned above, if its initial amplitude was larger than the critical amplitude, even though the basic flow was linearly stable in the upper layer or the basic flow was not small near the coast.

This process suggests some possibility that the frontal disturbance propagates southward along the Sanriku coast with a phase speed of shelf waves, after warmer sea water spread in the eastern sea area of the Tsugaru Strait. The frontal disturbance traveling southward

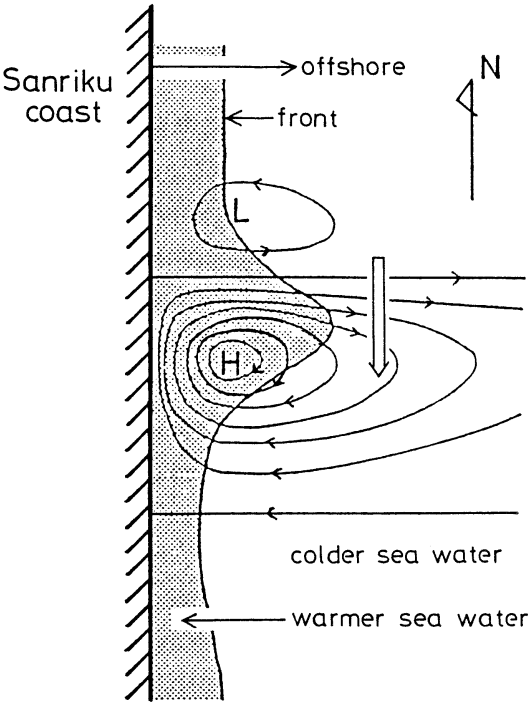


Fig. 16. Schematic diagram of circulation of cold sea water in the lower layer and growing solitary disturbance (wavelike front). The shadow indicates the warm water, and the solid lines represent the stream lines in the lower layer. This indicates that the cold sea water in the lower layer flows ashore at downstream side (southward) of wavelike front and the pycnocline becomes shallower (by KUBOKAWA, 1988b).

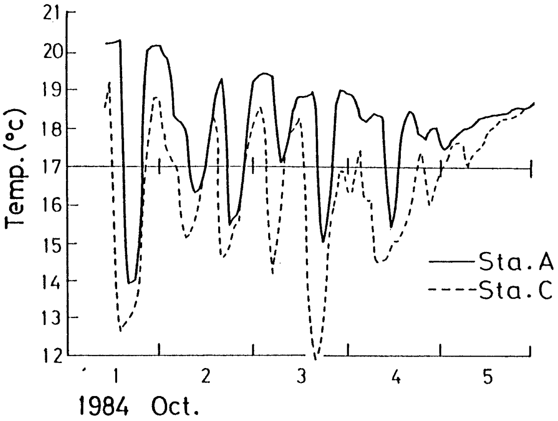


Fig. 17. Comparison of sea water temperature fluctuations at the bottom of Sta. A with those at the bottom of Sta. C (Oct. 1-5, 1984). —, Sta. A (at the bay head). -----, Sta. C (at the bay mouth).

is accompanied by clockwise circulation in the lower layer at the downstream side (southward) of the peak of the frontal disturbance (the convex-shaped front) and counterclockwise circulation in the lower layer at the upstream side (northward) of the peak (Fig. 16). For this reason, the sea water in the lower layer tends to flow ashore and then the pycnocline becomes shallower in the southern coastal sea area of the peak of the frontal disturbance. Therefore, when the frontal disturbance approaches the northeastern sea area of Toni Bay, the pycnocline (thermocline) becomes shallower in the coastal sea area near Toni Bay (KUBOKAWA, 1987, 1988a, b).

It was speculated that the internal long period waves were related to the behavior of the frontal disturbance offshore of Sanriku. It is important that some evidence for the existence and the propagation of the internal long period waves was obtained from the observation record in the coastal seas and was supported by a theoretical model study.

2) Propagation of the internal tidal waves into shallow bay

a) Phase speed and direction in propagation of the internal tidal waves

The propagation speed of the internal tidal waves was in the range of 35-50 cm/sec from the phase lag in sea water temperature records at the bottom between Sta.C and Sta.A and the distance between them (Fig. 17). If the median value, 42 cm/sec, was a typical propagation speed, the wave length of the semidiurnal internal tidal wave (L) was estimated about 20km (16-23 km, L = phase velocity × period (12.5 hours)). Those waves traveled from the northeast as estimated by the cross correlations of velocity components (U) at Stations B, C, D in Toni Bay (Fig. 1). MATSUNO (1989) reported that the propagating direction of the internal tidal wave in his observation was from the east in the Joban coastal seas. This difference in the direction

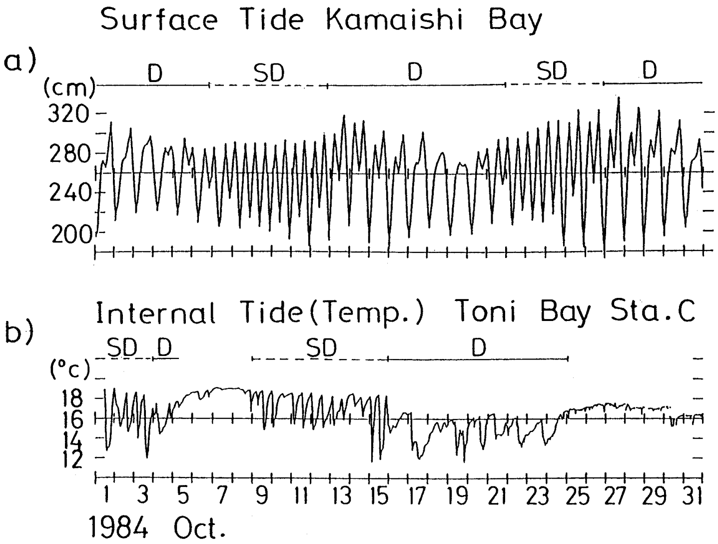


Fig. 18. Records of sea surface tide and the internal tide (sea water temperature) (Oct. 1–31, 1984). D, term of diurnal period fluctuation. SD, term of semidiurnal period fluctuation. a) Sea surface tide at Kamaishi Bay. b) Sea water temperature at Sta. C bottom in Toni Bay.

of propagation might be due to the offshore bottom configuration as a source area of the internal tidal wave.

The relation of the surface tide and the internal tidal wave

The period type is shown as D or SD in Fig. 18; "the day of diurnal period type (D)" was defined as the day when one in two peaks of fluctuation in a day was less than half of the other, and "the day of semidiurnal period type (SD)" was defined as two peaks of fluctuation in a day were comparable in amplitude. The surface tide was compared with the internal tide (subsurface water temperature); the internal tide had a semidiurnal period but the surface tide had a diurnal period for 1–3 October. Both had a semidiurnal period for 9–12 October, and the surface tide had a diurnal period but the internal one had a semidiurnal period for 13–15 October. For 16–21 October, both of them had a diurnal period. The surface tide was different in the period type from the internal tide for 22–24 October. INABA (1981) reported that in Suruga Bay the internal tide (tidal current) was predominant in the diurnal fluctuation from the observations of currents in the subsurface layer but the surface tide was prevailing in the semidiurnal fluctuation. The relation between them in Toni Bay was more complicated than that in Suruga Bay.

The surface tide already had a diurnal period on 1 October and the beginning day of a diurnal period was unknown, but the internal tide changed to the diurnal period on 4 October. The surface tide changed to the diurnal period on 13 October, and the internal one changed on 16 October. The beginning day of the diurnal period in the internal tide seemed to be 3–4 days behind that in the surface tide. If the internal tidal waves were generated far offshore by obtaining energy from the surface tide, the internal tidal waves with lower propagation speed than that of the surface tide must arrive at the coast behind the surface tide and both of the period types did not coincide at the coast. If the delay time of the internal tidal wave was 3–4 days and its propagation speed was 42 cm/sec, the generation area of the internal tidal wave was estimated at about 110–150 km offshore. The northeast sea area at 110–150 km from Toni Bay was the edge zone where the sea bottom configuration changed from the conti-

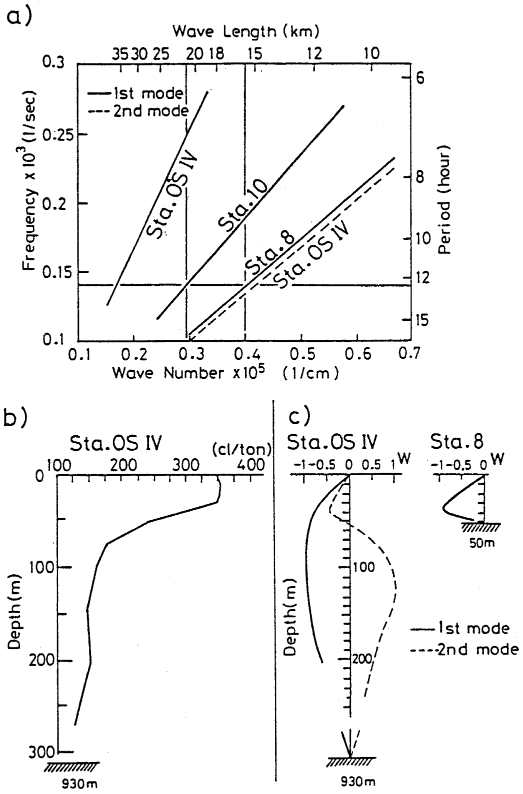


Fig. 19. Comparison of the dispersion relations of the internal tidal waves in Toni Bay with those offshore. a) Comparison of the dispersion relations: thick line, 1st mode; broken line, 2nd mode; thin line, wave length range at semidiurnal period. b) Vertical distribution of specific volume anomaly (cl/ton) of sea water at Sta. OSIV offshore. c) Comparison of vertical distributions of the vertical velocity at Sta. 8 with those at Sta. OSIV. Abscissa, ratio to maximum velocity.

nental slope to the slope of the Japan Trench.

b) Relationships between offshore internal tidal waves and those in Toni Bay

Comparison of the dispersion relations of the internal wave in a bay with that offshore

The internal tidal waves are able to propagate into a shallow bay only in the case of a thermocline formed initially in a bay. Fig. 19a shows the dispersion relations of the internal waves calculated from the vertical distribution of sea water density observed at stations inside and outside of Toni Bay. The dispersion relations of the internal wave at Sta. 8 and Sta. 10 were calculated as the representative data in the bay, and Sta. OSIV (930 m depth, 36 km offshore) was a representative offshore station and the vertical distribution of the specific volume anomaly of sea water at Sta. OSIV was shown in Fig. 19b. If the period was semidiurnal, the wave length of the 1st mode at Sta. OSIV was 35-40 km, and this was inconsistent with the estimated wave length (about 20 km) from observations in Toni Bay (Fig. 19a). The dispersion relation of the 2nd mode at offshore Sta. OSIV was very similar to that of the 1st mode at Sta. 8 and Sta. 10 in the bay. In this semidiurnal internal wave, the wave length was 16-23km from the estimated speed of 35-50 cm/sec from observations in the bay (thin lines in Fig. 19a show this range). This wave length (16-23km) was easy to resonate with the length of Toni Bay (about 5 km; length of area deeper than 20 m depth). The properties of the 1st mode of the internal tidal waves in the bay were nearly equal to those of the 2nd mode of the internal tidal waves outside of the bay, and the vertical distribution of vertical velocity (W, cm/sec) was also similar in the internal waves inside and outside of the bay (Fig. 19c).

In conclusion, these results showed that the 2nd mode of the internal tidal wave offshore was well related to the 1st mode of that in Toni Bay.

Comparison of propagation ratio of the energy of the internal wave into shallow bay

The probability that the 1st or the 2nd mode of the internal waves offshore propagates into a bay was studied by analytical calculation in a simple model in which the depth in the bay was 50 % of the depth outside of the bay and the basic condition of the vertical distribution of sea water density (ρ) outside of the bay was a constant Brunt-Väisälä Frequency, $N^2 = -(g/\rho) \times (\partial\rho/\partial z)$ (CRAIG, 1987). The left in Fig. 20a is the case of initially given the 1st mode of the internal wave outside of the bay, and the density of stream lines indicates the energy

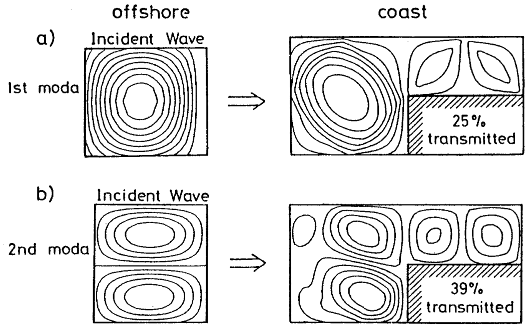


Fig. 20. Transport efficiency of the internal wave energy propagating into the shallow bay from the offshore sea. Solid lines represent stream lines. a) The case that the incident wave is the 1st mode of the internal wave. b) The case that the incident wave is the 2nd mode of the internal wave.

level. The right in Fig. 20a is the distribution of stream lines after the internal wave propagated into a shallow bay, and it shows that the wave energy transported into the bay is 25 % of the offshore incident wave energy. The case of initially given the 2nd mode of the internal wave outside of the bay is shown at left in Fig. 20b. In this case, it is indicated that 39% of the wave energy of the 2nd mode of the offshore incident wave propagate into the bay. It is sure that more energy of the 2nd mode of the offshore internal wave propagates into the bay than the energy of the 1st mode of that wave.

Shoaling up of the internal tidal waves into the bay

As mentioned in chapter 3, the record of the internal tidal waves as fluctuations of the sea water temperature in the bottom layer suggested that there were two cases for the propagation of the internal tidal waves into a bay. The first was the general case of the internal wave, and the internal tidal waves propagated through the thermocline which was already formed in the bay. The second was the case of no thermocline initially in the bay and the thermocline was formed after colder sea water flowed into the bottom layer of the bay. In the second case, therefore, the thermocline in the bay disappeared in every cycle of the tidal period.

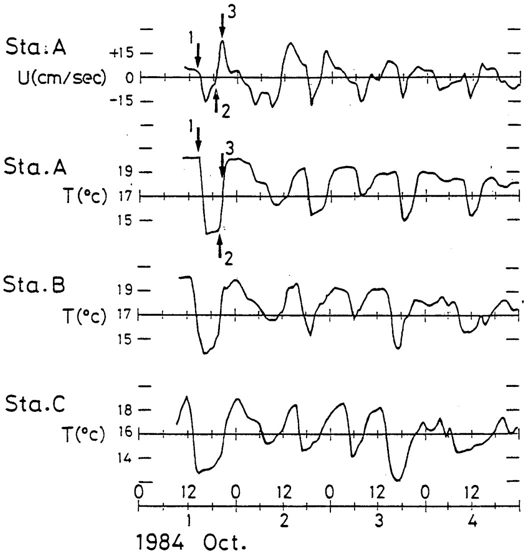


Fig. 21. Fluctuation patterns of sea water temperature and velocity component at bottom in Toni Bay (Oct. 1-4, 1984).

Semidiurnal periods for 1-3 and 9-15 October corresponded to the second case, because the sea water temperature in the bottom layer rose to near the sea surface water temperature in every tidal cycle (Fig. 6). After the colder sea water in the bottom flowed out of the bay, the thermocline disappeared in the bay. If the thermocline remained always in the bay and the internal tidal wave was dominant, a thermometer (contained in the current meter) in the bottom layer stayed always in the colder sea water under the thermocline (the general case), and the sea water temperature in the bottom layer should remain at 15-16℃ (Fig. 6). However, the sea water temperature in the bottom layer was found at 19℃, near that in the surface layer (about 20℃) in the record. In particular, for 9-15 October, the maximum sea water temperature in the bottom layer agreed almost with that in the surface layer. This suggested that "a colder sea water front" shoaled up on the bottom of the bay every semidiurnal tidal cycle.

The raw records of velocity (eastward component (U), in the bottom layer at Sta.

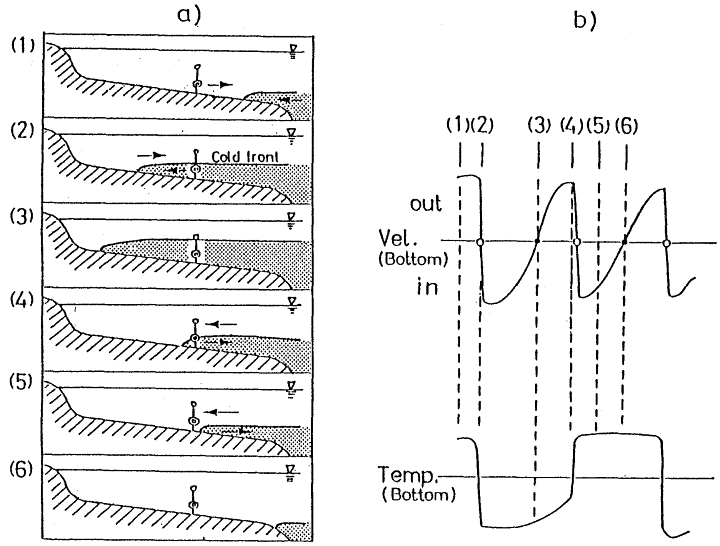


Fig. 22. Schematic pictures of shoaling up of the colder sea water front, and the corresponding figure of variations of velocity and sea water temperature at the bottom in the bay. a) Schematic pictures of the moving cold front : (1) cold front starts to flow into bay, (2) cold front passes the station into bay, (3) cold front stops at head of bay, (4) cold front flows out of bay, (5) cold front passes the station out of bay, (6) cold front stops out of bay. b) Schematic figure of variations of the velocity component and sea water temperature at the bottom in the bay. (1)-(6) correspond to (1)-(6) in figure (a).

A) and the sea water temperature (in bottom layer at Stations A, B, C) for 1-4 October are shown in Fig. 21. Fluctuation curves of the sea water temperature are not a sinusoidal pattern but have a peculiar pattern. On 1 October, the sea water temperature fell and rose suddenly at all stations and they were different from a sinusoidal wave. If it was the general case (the first case), the changes of the sea water temperature and that of direction of velocity (U) must occur simultaneously in the time when the thermocline passed the station of the thermometer (as shown by arrows 1 in Fig. 21). But, Fig. 21 showed that the sea water temperature changed at a different time from the change in the direction of velocity (as shown by arrows 2 in Fig. 21). At Sta.A, at 14:00 on 1 October when the flow changed suddenly from outward (U > 0) to inward (U < 0), the sea water temperature changed simultaneously to colder suddenly (arrows 1), but at 19:00 when the flow changed to outward, the sea water temperature was steady (arrows 2), and when the speed of the flow reached positive maximum, the sea water temperature began to be warmer (arrows 3).

The time interval of the minimum temperature on 1 October in the bay mouth (Sta.C) was longer than that in the bay head (Sta.A). This suggested that the flow in the bottom of the bay was not the internal wave case with steady thermocline in the bay, but was the shoaling up and down of the colder sea water front on the bottom of the bay.

The process of the shoaling up and down of the colder sea water front in the bay will be inferred in the schematic picture (Fig. 22).

At the beginning, the colder sea water front starts shoaling up from the bay mouth into the bay which is filled with warmer sea water only, and the flow at a station of the thermometer is outward (U>0), (1) in Fig. 22. When the colder front passes the station toward the bay head, the direction of velocity changes to flow inward (U<0) and the sea water temperature falls abruptly to the minimum, (2). The colder sea water front keeps on flowing inward and then stops at the bay head, (3). When the internal tide starts to ebb, the colder front at the bay head starts to shoal down and the direction of the flow at the station changes to outward of the bay (U>0), but the sea water temperature remains at almost the minimum, (4). When the colder front passes the station toward the bay mouth, the direction of velocity changes inward (U<0) and the sea water temperature rises suddenly up to the maximum, (5). Afterward, the colder front continues to flow outward and stops outside of the bay, (6). At this time, there is only the warmer water in the bay. Those variation patterns were similar to the variation patterns of the observed record of 1-2 October (Fig. 21).

In the case of the semidiurnal fluctuations in the beginning of October, it was concluded that the occurrence of the stratified structure in Toni Bay was temporal and cyclic, and the propagation of the semidiurnal internal tidal wave into the bay must be the shoaling up of the cold sea water front.

CAIRNS (1967) reported on the internal tidal bore in the shallow sea off south California, from the variation pattern of the water temperature observed by thermister arrays. His variation pattern was similar to the shoaling up in Toni Bay, and the shoaling phenomenon seemed to be considerably important in the exchang of the sea water in a shallow bay.

5. Summary

A study of the internal tidal waves in a small bay was carried out on the basis of the observed records in Toni Bay, autumn 1984.

1. The internal tidal waves in the bay were predominant and had the characteristics of intermittent occurrence in several days. From T-S diagram analyses of the sea water property at stations inside and outside of the bay, the property of the sea water in the bottom layer was closely related to that of offshore sea water in the layer (70-100 m deep, this was the depth under a thermocline) a little deeper than the bottom layer in the bay. It was found that the intermittency of the internal tidal waves was related to the vertical displacement of the thermocline outside of the bay, namely the internal tidal waves appeared in the bay predominantly when the thermocline became shallower.

2. The cause of the intermittent vertical displacement of the thermocline was investigated through the analyses of (a) variations in subsurface water temperature and (b) variations of the local difference of tidal deviations (sea surface level anomaly) at three stations along the Sanriku coast.

a) The cross correlation of variations of the sea water temperature in the surface layer between in Toni Bay and in Otsuchi Bay was very high with a correlation coefficient (α) of 0.89, and the phase of the variation in Otsuchi Bay was in advance of that in Toni Bay. It was found that the variation of the sea water temperature (variation of the thermocline depth) propagated southward at a speed of about 19 cm/sec. This was considerably lower than the wave speed of a coastal trapped wave (internal Kelvin wave, more than 30 cm/sec). The variation of the thermocline depth seemed to be due to a kind of the internal long period wave propagating southward alongshore.

This propagation speed was similar to the southward propagation speed (16 cm/sec) of the pycnocline front with a convex shape at the offshore edge of the Tsugaru Warm Waters from satellite images. It was suggested that the internal long period waves were related to the behavior of the pycnocline front. Recent theoretical research showed that the frontal disturbance propagated as a coupled wave of Semigeostrophic Frontal Wave in the upper layer (KUBOKAWA and HANAWA, 1984) with the wave to be restored by potential vorticity in the lower layer. This frontal disturbance travels southward accompanied by clockwise circulation in the lower layer at the downstream side of the peak of the front (KUBOKAWA, 1987, 1988a, b), where the sea water in the lower layer tends to flow onshore and the thermocline becomes shallower. These features and the lower propagation speed of the frontal distribution were in good agreement qualitatively with those of the internal long period waves.

b) When the internal long waves propagate along the coast, it is expected that the sea surface level changes out of phase to the depth of the thermocline, even if it is very small. When the sea level at Kamaishi minus that at Miyako ($\Delta\zeta_{KM}$) was negative, the thermocline off Toni Bay (near Kamaishi Bay) must become shallower. Accordingly, the cold sea water offshore was able to intrude into the bottom of the bay, and the duration of negative $\Delta\zeta_{KM}$ corresponded to that of the predominant internal tide in the bay near Kamaishi. $\Delta\zeta_{KM}$ was highly correlated with the variation of the sea water temperature in the bottom layer of Toni Bay; the correlation coefficient (α) was 0.68. Another local difference ($\Delta\zeta_{OK}$) between Ofunato and Kamaishi was out of phase with $\Delta\zeta_{KM}$, which supported also the alongshore propagation of the internal long period waves. The results indicated the existence of the internal long period waves propagating alongshore with a suitable space scale to their time scale, because the distance between Miyako and Kamaishi (45 km) was nearly a half wave length of the wave with time scale of several days and wave speed of 19 cm/sec.

The internal long period waves were independent of the internal tidal waves in their generation and propagation. The internal tidal waves appearing intermittently in the bay occurred from the superposition of the internal tidal waves propagating onshore and the internal long period waves propagating alongshore.

3. The propagation speed of the internal tidal waves was estimated about 42 cm/sec (35-50 cm/sec) from the observations. The source area of the internal tidal waves was roughly estimated at 110-150 km northeast from Toni Bay. The dispersion relation of the 1st mode of the internal waves in the bay was similar to that of the 2nd mode offshore. Moreover, the vertical distribution of the vertical veloctity of the 1st mode of the internal waves in the bay was quite similar to that of the 2nd mode offshore. From the dispersion relations, the phase speed of the semidiurnal internal tidal waves was calculated aboout 40 cm/sec which was consistent with the phase speed estimated from the time lag of observed records mentioned above.

The energy flux transported into the bay due to the 2nd mode of the offshore internal wave was 1.6 times greater than that due to the 1st mode of the wave in an analytical calculation in a simple model. The semidiurnal internal waves in Toni Bay were closely related to the 2nd mode of the internal waves offshore.

In addition, it was suggested that the semidiurnal internal tidal waves shoaled up with the intrusion of a cold sea water front from offshore into the bottom layer of the bay.

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References

CAIRNS, J. L. (1967): Asymmetry of internal tidal waves in shallow coastal waters. J. Geophys. Res., **72**, 3563-3565.

CRAIG, P. D. (1987): Solutions for internal tidal generation over coastal topography. J. Mar. Res., **45**, 83-105.

HANAWA, K. (1984): Coastal boundary current. Bull. Coastal Oceanogr. Japan, **22**, 67-82. (in Japanese)

HOLLOWAY, P. E. (1984): On the semidiurnal internal tide at a shelf-break region on the Australian northwest shelf. J. Phys. Oceanogr., **14**, 1787-1799.

HOLLOWAY, P. E. (1985): A Comparison of semidiurnal internal tide from different bathymetric locations on the Australian northwest shelf. J. Phys. Oceanogr., **15**, 240-251.

INABA, H. (1981): Circulation pattern and current variations with respect to tidal frequency in the sea near the head of Suruga Bay. J. Oceanogr. Soc. Japan, **37**, 149-159.

KUBOKAWA, A. (1986): Instability caused by the coalescence of two modes of one-layer coastal current with a surface front. J. Oceanogr. Soc. Japan, **42**, 373-380.

KUBOKAWA, A. (1987): Instability and nonlinear evolution of a density-driven coastal current with a surface front in a two-layer ocean. Kaiyou Kagaku (Marine Science), **19**, 48-52. (in Japanese)

KUBOKAWA, A. (1988a): Instability and nonliner evolution of a density-driven coastal current with a surface front in a two-layer ocean. Geophys. Astrophys. Fluid Dyn., **40**, 195-223.

KUBOKAWA, A. (1988b): Theoretical models of the variations of surface density fronts and possible application to the Tsugaru Warm Current. Bull. Tohoku Reg. Fish Res. Lab., **50**, 131-136. (in Japanese)

KUBOKAWA, A. and K. HANAWA (1984): A theory of semigeostrophic gravity waves and its application to the intrusion of a density current along a coast. Part 1 Semigeostrophic gravity waves. J. Oceanogr. Soc. Japan, **40**, 247-259.

KUBOTA, M. (1982): Continental shelf waves off the Fukushima coast. Part 2 Theory of their generation. J. Oceanogr. Soc. Japan, **38**, 323-330.

KUBOTA, M. (1985): Continental shelf waves off the Fukushima coast. Part 3 Numerical experiments. J. Oceanogr. Soc. Japan, **41**, 105-112.

KUBOTA, M., K. NAKATA and Y. NAKAMURA (1981): Continental shelf waves off the Fukushima coast. Part 1 Observations. J. Oceanogr. Soc. Japan, **37**, 267-278.

MAGAARD, L. and W. D. MCKEE (1973): Semidiurnal tidal current at 'site D'. Deep-Sea Res., **20**, 997-1009.

MATSUNO, K. (1989): Internal tides off the coast of Fukushima, east of Japan. Rep. Mar. Ecol. Res. Inst., **89302**, 1-28. (in Japanese)

MATSUYAMA, M. (1985): Internal tide in Uchiura Bay: Subsurface temperature observations near the bay head. J. Oceanogr. Soc. Japan, **41**, 135-149.

MATSUYAMA, M. (1987): Internal tide near Suruga Bay and Sagami Bay. Kaiyou Kagaku (Marine Science), **19**, 470-477. (in Japanese)

NISHI, K. and H. KUNISHI (1985): Ocean characteristics and its changes. Report of Special Project Research (ed. K. KAJIURA), Min. Educ. Sci. Cult., 212-221. (in Japanese)

SHIKAMA, N., T. KAWAMURA, T. TANAKA, K. IWAMA, A. TADA and K. IWAITA (1985): Records of routine observation on weather and sea condition. Otsuchi Mar. Res. Cent. Rep., **12**, 193-218. (in Japanese)

TSUJITA, T. (1974): Circulation and mixing of sea water in Toni Bay. Report on Researches of Tidal Current in Toni Bay, 2-10. (in Japanese)

WUNSCH, C. (1975): Internal tides in the ocean. Rev. Geophys. Space Phys., **13**, 167-182.

YASUDA, I., M. HIRAI, K. OKUDA, Y. OGAWA, H. KUDOU, S. FUKUSHIMA and K. MIZUNO (1987): Short period variations of Tsugaru Warm Current and fishery fields of mackerel. Kaiyou Kagaku (Marine Science), **19**, 40-47. (in Japanese)

三陸沿岸における内部潮汐波と内部長周期波

岡 嵜 守 良

要旨: 内湾における内部潮汐波の特性について，1984年秋季，三陸沿岸の唐丹湾において行われた観測を基に，解析を行い次の事がわかった。

i）湾内の顕著な内部潮汐波は長期間連続的に現れるのではなく，数日程度の間欠性がみられた。湾内外の海水のT-S図解析の結果，この間欠性が水温躍層の深さの変動に関係していることが判明した。その間欠的上昇に応じて湾内底層に冷海水が流入して成層構造が形成され，内部潮汐波が間欠的に湾内に出現するものと考えられた。

ii）このような間欠的な水温躍層の深さの変動の原因を究めるため，唐丹湾近傍の2つの湾の水温変動の相関を調べ，また3つの湾の海面水位の変動と水温躍層の鉛直変動との関連を調べた。その結果，水温躍層は海岸に沿って北から南へ伝わる内部長周期波によって上昇することが示唆された。この内部長周期波は約19cm/secで南進し，約100km程度の空間規模を持っていることが示された。これは北東から岸向きに伝播する内部潮汐波とは独立な波であり，これら2つの波が重畳したときに，湾内の内部潮汐波に間欠性が現れる。この他，この内部長周期波は津軽暖水域東端の密度フロントの南への波動的伝播に関連のあることが示唆された。

iii）湾内外の観測データから求めた内部潮汐波の分散関係や波速等の比較，及び簡単なモデルによる沖合の内部波エネルギーの湾内への伝播効率の比較等の結果，湾内の卓越した半日周期の内部潮汐波は沖合のそれの第２モードに関連の深いことが示唆された。

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Density fluctuation of caprellid amphipods (Crustacea) inhabiting the red alga *Gelidium amansii* (LAMOUROUX) LAMOUROUX, with emphasis on *Caprella okadai* ARIMOTO*

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Abstract: Species composition and density fluctuation of caprellid amphipods inhabiting a red alga *Gelidium amansii*, which is a true-perennial alga, were investigated in a small inlet of the rocky shore facing the Pacific Ocean, at Amatsu-Kominato, Chiba Prefecture. Six caprellid species were found to be present. Among them *Caprella okadai* was the most dominant species. Its share in the caprellid fauna was more than 67 % throughout the year. The density during May to August was 10 times higher than that during September to March, and mature females were found almost all the time. Several species of *Caprella* which inhabit *Sargassum* spp. have been reported to exhibit different occurrence pattern, suggesting that life forms of algae influence the occurrence of caprellids. Review of distribution of *C. okadai* reveals that this species is restricted to calmer zones of rocky shore facing the open sea.

1. Introduction

Caprellid amphipods, as well as gammarid amphipods, represent an important component in the ecosystem of "Garamo-ba" (*Sargassum* zone) which flourishes on rocky shores of southern Japan, as these crustaceans are the major predated forms by rocky shore fishes (FUSE, 1962; HIRAYAMA, 1978; KANAMOTO, 1977, 1979; OMORI, 1980). Ecological studies on the caprellids on the "Garamo-ba" have mostly dealt with either substrate selection (HIRAYAMA and KIKUCHI, 1980; IMADA *et al*., 1981; NORTON and BENSON, 1983; TAKEUCHI *et al*., 1987; TAKEUCHI *et al*., MS) or population dynamics (IMADA and KIKUCHI, 1984; AOKI, 1988). These studies, however, are usually restricted to animals collected from the *Sargassum* species which are larger algae among various kinds of algae found in "Garamo-ba". Only HIRAYAMA and KIKUCHI (1980) and TAKEUCHI *et al.* (1987) reported on caprellid species compositions on several species of smaller algae on the basis of seasonal collections.

In this study, we focus on species composition and density fluctuation of the Caprellidea inhabiting the red alga *Gelidium amansii* (LAMOUROUX) LAMOUROUX, which is a true perennial alga (KATADA, 1963).

2. Materials and Methods

This study was conducted in the innermost part of an inlet called "Jizogi" (Fig. 1) in the vicinity of the Kominato Marine Biological Laboratory of the Tokyo University of Fisheries (KMBL) (now the Kominato Marine Laboratory, Faculty of Science, Chiba University). This inlet is situated on the southwest of Uchiura Bay facing the Pacific Ocean. Sampling was carried out from the center of a thick community of *Gelidium amansii* at the depth of 1.3 m.

Duplicate samples of *G. amansii* from a quadrat of 20 × 20 cm were collected by skin diving at monthly intervals from April 1978 to March 1979. Algae were gently removed and quickly placed in a vinyl bag. In the laboratory, the algae were shaken in freshwater for dislodging free-living epifauna. Caprellids were carefully sorted out and preserved in 10

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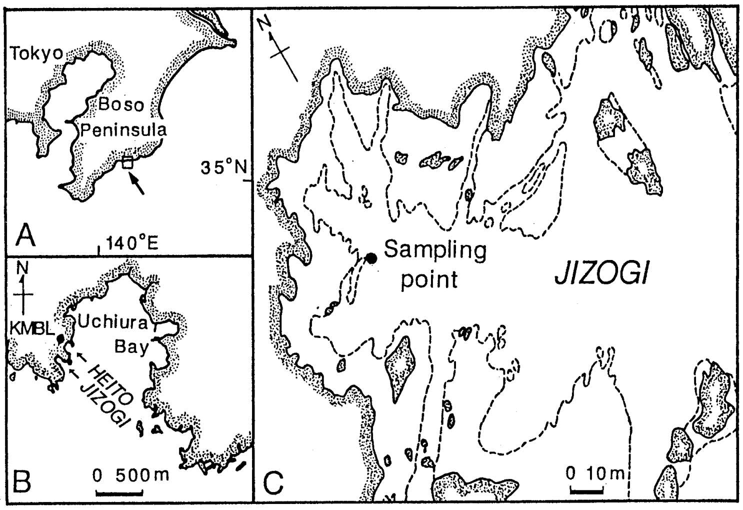

Fig. 1. Maps showing the study site. A. Boso Peninsula. Marked area (arrow) indicates the location of Uchiura Bay. B. Uchiura Bay. KMBL: Kominato Marine Biological Laboratory, Tokyo University of Fisheries. C. Map of Jizogi showing the sampling point. Broken lines indicate the highest low water during the neap tide.

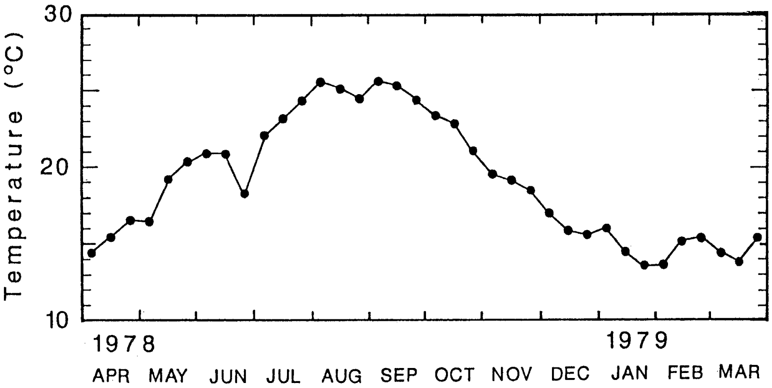

Fig. 2. Seasonal change of seawater temperature based on the daily observation records of the former Kominato Marine Biological Laboratory, Tokyo University of Fisheries. Each solid circle indicates the average temparature for the first, second and last 10 days in every month.

% buffered formalin. Caprellid species identification was conducted under a binocular microscope. Sex of *Caprella okadai*, the most dominant species, was determined from the development of gnathopod in males and the presence of oostegites in females. The other small individuals which did not possess the sexual characters were classified as juveniles. Furthermore, females were separated into two categories, i. e. immatures in which oostegites are without setae, and matures in which oostegites with long setae form a brood pouch. Wet weight of algae was measured to the nearest g after leaving them on papers for two hours.

Seawater temperature data based on the daily observation record of KMBL have been used in the present study. It ranged from 13.2 to 25.5℃ (Fig. 2). Salinity variation was restricted to 33.1–34.0‰ during the period of the investigation (HAYASHI, 1989).

3. Results

The wet weight of *Gelidium amansii* per 400 cm^2 varied from 80 to 175 g and no seasonal fluctuation was recognized.

Six species of the Caprellidae were collected. All these six species belong to the genus *Caprella*; *C. okadai* ARIMOTO, 1930, *C. simia* MAYER, 1903, *C. kominatoensis* TAKEUCHI, 1986, *C. penantis* LEACH, 1814, *C. decipiens* MAYER, 1903 and *C. generosa* ARIMOTO, 1977. The last species is the same as *Caprella* sp. III reported from Amatsu-Kominato by TAKEUCHI *et al.* (1987).

C. okadai was the most dominant species throughout the year. The share of *C. okadai* to total number of caprellids varied from 67 to 100 % (Fig. 3). Its individual density per 100 g wet weight of the alga increased rapidly from April to May and was kept high until August (> 150 ind./ 100 g wet weight) (Fig. 4). In September, it decreased to 16.2 ind./ 100 g wet weight, and such a low density (< 50 ind./ 100 g wet weight) extended up to March. The density pattern based on their abundance per 400 cm^2 bottom area in the quadrat sample also showed a similar projection (Fig. 4).

Juveniles, i. e. those individuals which had a body length less than 4.0 mm, constituted the bulk of the population throughout the year except in August and November (Table 1). Mature females were also collected throughout the year, except during January 1979. This indicates that *C. okadai* could mature and produce eggs all the year round in this area, where seawater temperature varied between 13 and 26℃ (Fig. 2).

The second dominant species was *C. simia*. Its maximum share was only 33 % and was encountered in October 1978 (Fig. 3). In July and August, its density was relatively high (15.4 and 5.9 ind./ 100 g wet weight, respectively), but in other months it was less than 2.0 ind./ 100 g wet weight. Mature females were not found.

4. Discussion

In this study, *Caprella okadai* was found to be exclusively dominant throughout the year on the red alga *Gelidium amansii* in the inner part of the inlet (Fig. 3). Although we did not measure the length of algae, it is estimated to range from ca. 15 to 20 cm throughout the year. TAKEUCHI *et al.* (1987) report-

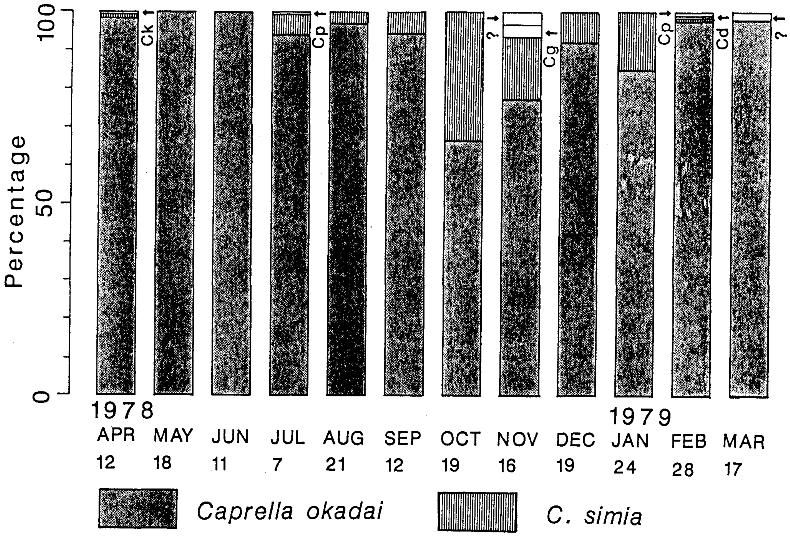

Fig. 3. Seasonal fluctuation in species composition of the Caprellidae associated with *Gelidium amansii* (LAMOUROUX) LAMOUROUX. Cd, *Caprella decipiens* MAYER; Cg, *C. generosa* ARIMOTO; Ck, *C. kominatoensis* TAKEUCHI; Cp, *C. penantis* LEACH; and ?, unidentified individuals due to damages.

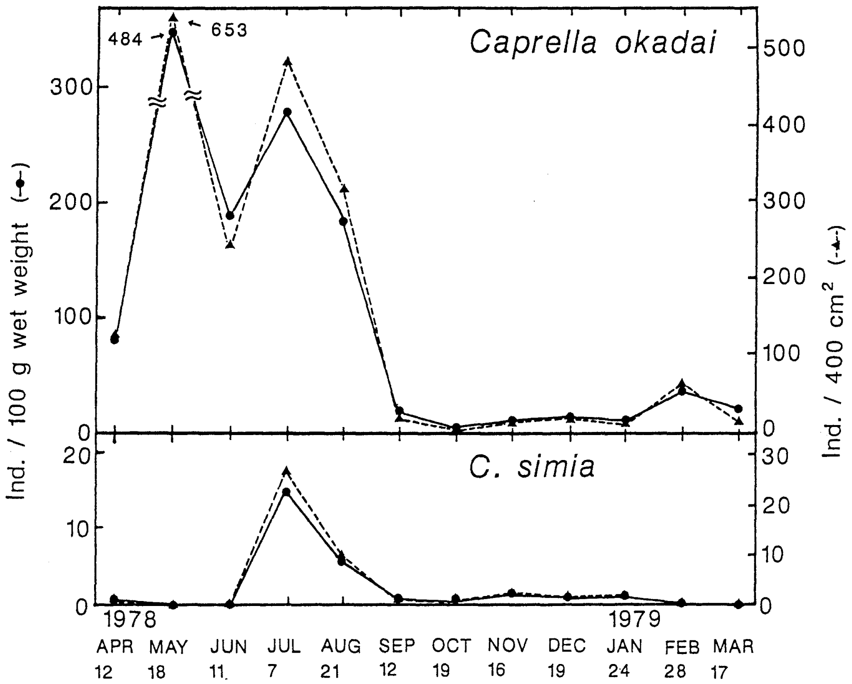

Fig. 4. Seasonal fluctuation in the density of *Caprella okadai* ARIMOTO and *C. simia* MAYER. Solid circle: the number of individuals per 100 g wet weight of *Gelidium amansii* (LAMOUROUX) LAMOUROUX. Solid triangle: the number of individuals per 400 cm² of bottom area.

Table 1. Seasonal variations in proportion (%) of juveniles, males, immature and mature females to the total individuals and sex ratio (males/females) of *Caprella okadai* ARIMOTO.

	1978 12 Apr.	18 May	11 June	7 July	21 Aug.	12 Sept.	19 Oct.	16 Nov.	19 Dec.	1979 24 Jan.	28 Feb.	17 Mar.
Juveniles	76.4	84.8	67.1	51.3	30.5	47.1	50.0	16.7	60.0	52.2	55.2	46.2
Males	11.8	5.7	14.0	17.6	28.6	26.4	25.0	41.7	25.7	21.7	15.2	28.8
Females												
immatures	10.0	4.9	10.2	20.3	17.9	14.7	0.0	33.3	2.9	26.1	18.4	17.3
matures	1.8	4.6	8.7	10.8	23.0	11.8	25.0	8.3	11.4	0.0	11.2	7.7
Sex ratio	1.00	0.60	0.74	0.57	0.70	1.00	1.00	1.00	1.80	0.83	0.51	1.15

Juveniles 1.5 - 4.0mm, males 4.0 - 8.5mm, immature females 3.5 - 6.0mm and mature females 4.5- 8.0mm in body length.

ed that *C. okadai* was the dominant species on such large algae (>10cm) as *G. amansii*, *Cladophora wrightiana* HARVEY and *Sargassum piluliferum* (TURNER) C. AGARDH, which were growing at the zones protected from wave exposure in the inlet "Heito". This inlet is located to the north of "Jizogi" (Fig. 1). The present results support their conclusion.

Year-round breeding in different species of *Caprella*, similar to the present observation on *C. okadai*, has been reported in studies carried out in the temperate region; *C. penantis* (BYNUM, 1978; CAINE, 1983), *C. laeviuscula* MAYER (CAINE, 1979), *C. californica* STIMPSON (KEITH, 1971), *C. equilibra* SAY (KEITH, 1971), *C. gorgonia* LAUBITZ and LEWBEL (LEWBEL, 1978), *C. tsugarensis* UTINOMI (IMADA and KIKUCHI, 1984), *C. decipiens* (IMADA and KIKUCHI, 1984) and *C. verrucosa* BOECK (AOKI, 1988).

The occurrence of caprellids is influenced by the life forms of algae with which caprellids are associated. In this study, *C. okadai* was collected throughout the year, and the high density was recorded during May to August. However, the occurrence of *C. danilevskii* CZERNIAVSKI, *C. tsugarensis* and *C. decipiens*, which were associated with the brown alga *Sargassum horneri* (TURNER) C. AGARDH, was restricted from fall to early summer (IMADA and KIKUCHI, 1984). Similar seasonal fluctuation was also observed in the case of *C. verrucosa* on *S. patens* C. AGARDH (AOKI, 1988). *S. horneri* is an annual alga (TERAWAKI *et al*., 1983b; TERAWAKI, 1986), and the entire thalli flowed away during spring to early summer (IMADA and KIKUCHI, 1984). The larger parts of *S. patens* thalli, which is a stem-survived perennial species (KATADA, 1963; TERAWAKI *et al*., 1983a), also flowed away during late spring to early summer, leaving behind short round stems only (AOKI, 1988). TAKEUCHI *et al*. (1987) reported that *C. okadai*, *C. danilevskii, C. tsugarensis* and *C. decipiens* were mostly collected from large algae (> 10 cm) which possess filamentous or long thalli. All these four species of *Caprella* are typically similar in having an elongate body with a sharp and short basis of gnathopod II. They observed that these caprellids, except *C. decipiens*, clung the substrata by gnathopod I and pereopods V-VII with body straightened. This reveals a possibility that morphological characteristics of caprellids might have adapted to the feature of algae. Hence, the presence of suitable feature of algae for clinging is one of the most important factors which have influence on the occurrence of caprellid amphipods. Therefore, these species of *Caprella* associated with *S. horneri* and *S. patens* could not be collected during the summer.

This conclusion is also supported by the result of a comparative study on populations of *Caprella penantis* collected from two sites along the Atlantic Ocean of North Carolina (BYNUM, 1978). He compared the population structure of this caprellid from the estuarine site where hydroids and bryozoans were the most common substrate and that from the coastal site where red and green algae predominated. Population at each site peaked during July. During late August, the caprellid density at estuarine site rapidly decreased with disappearance of *Tubularia crocea*, a common hydroid, while the high density continued to prevail at the coastal site.

Caprella okadai was reported first from Tateyama, Chiba Prefecture (ARIMOTO, 1930, 1976) and then from Tomioka, Amakusa-Shimoshima Island, Kumamoto Prefecture (IMADA *et al*., 1981) and Amatsu-Kominato (TAKEUCHI *et al*., 1987). Besides these records, one of the authors (IT) has also found it on several occasions in coastal waters of Japan, i.e. Nabeta Bay of Izu Peninsula, Shizuoka Prefecture, Unose on Amakusa-Shimoshima Island and Magari on Notojima Island, Ishikawa Prefecture. In all these instances, *C. okadai* was collected from the rocky shore facing the ocean influenced by either the Kuroshio Current or Tsushima Current. Since this species of *Caprella* has never been found in eutrophic bays such as the Seto Inland Sea, Ise Bay, Tokyo Bay, etc. until now, it can be presumed that the distribution of *C. okadai* is restricted to the areas protected from wave exposure of rocky shore facing the open sea.

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References

AOKI, M. 1988. Factors affecting population fluctuations of caprellid amphipods inhabiting *Sargassum patens* bed (Preliminary report). Benthos Res. [Bull. Japan. Ass. Benthology] (32): 42-49. (In Japanese with English summary)

ARIMOTO, I. 1930. Studies on the Caprellidae from Tateyama. II. Hakubutsu-Gakkaishi [J. Tokyo Nat. Hist. Soc.] **27**(39): 13-25. (In Japanese)

ARIMOTO, I. 1976. Taxonomic studies of caprellids (Crustacea, Amphipoda, Caprellidae) found in the Japanese and adjacent waters. Spec. Publ. Seto Mar. Biol. Lab., Ser. III: v + 229 pp.

BYNUM, K. H. 1978. Reproductive biology of *Caprella penantis* LEACH, 1814 (Amphipoda: Caprellidae) in North Carolina, U.S.A. Estuarine Coast. Mar. Sci. **7**: 473-485.

CAINE, E. D. 1979. Population structures of two species of caprellid amphipods (Crustacea). J. Exp. Mar. Biol. Ecol. **40**: 103-114.

CAINE, E. D. 1983. Community interactions of *Caprella penantis* LEACH (Crustacea: Amphipoda) on sea whips. J. Crust. Biol. **3**: 497-504.

FUSE, S. 1962. The animal community in the *Sargassum* belt. Physiol. Ecol., Kyoto **11**: 23-45. (In Japanese with English summary)

HAYASHI, I. 1989. Long-term records on the surface water temperature and salinity at the Kominato Marine Laboratory. Ann. Rep. Inst. Mar. Ecosystem, Chiba Univ. (9): 40-51. (In Japanese with English title)

HIRAYAMA, A. 1978. Life of 0 year black rockfish, *Sebastes inermis* CUVIER et VALENCIENNES, in the algal bed. Nanki Seibutsu **20**: 55-62. (In Japanese with English title)

HIRAYAMA, A. and T. KIKUCHI 1980. Caprellid fauna associated with subtidal algal beds along the coast of the Oshika Peninsula, Tohoku District. Publ. Amakusa Mar. Biol. Lab. **5**: 171-188.

IMADA, K., A. HIRAYAMA, S. NOJIMA and T. KIKUCHI 1981. The microdistribution of phytal amphipods on *Sargassum* seaweeds. Res. Crust. (11): 124-137. (In Japanese with English summary)

IMADA, K. and T. KIKUCHI 1984. Studies on some reproductive traits of three caprellids (Crustacea: Amphipoda) and their seasonal fluctuations in the *Sargassum* bed. Publ. Amakusa Mar. Biol. Lab. **7**: 151-172.

KANAMOTO, Z. 1977. On the ecology of hexagrammid fish. III. Niches of *Agrammus agrammus* (TEMMINCK et SCHLEGEL) and *Hexagrammos otakii* JORDAN et STARKS and the mode of life of some reef fish. Japan. J. Ecol. **27**: 215-226. (In Japanese with English summary)

KANAMOTO, Z. 1979. On the ecology of hexagrammid fish. IV. Mode of the distribution of *Agrammus agrammus* (TEMMINCK et SCHLEGEL) and *Hexagrammos otakii* JORDAN et STARKS and composition, abundance and food items of reef fish around several reefs. Japan. J. Ecol. **29**: 171-183. (In Japanese with English summary)

KATADA, M. 1963. Life forms of seaweeds and succession of their vegetation (Review). Bull. Japan. Soc. Sci. Fish. **29**: 798-808. (In Japanese with English title)

KEITH, D. E. 1971. Substrate selection in caprellid amphipods of southern California, with emphasis on *Caprella californica* STIMPSON and *Caprella equilibra* SAY (Amphipoda). Pac. Sci. **25**: 387-394.

LEWBEL, G. S. 1978. Sexual dimorphism and intraspecific aggression, and their relationship to sex ratios in *Caprella gorgonia* LAUBITZ & LEWBEL (Crustacea: Amphipoda: Caprellidae). J. Exp. Mar. Biol. Ecol. **33**: 133-151.

NORTON, T. A. and M. R. BENSON 1983. Ecological interactions between the brown seaweed *Sargassum muticum* and its associated fauna. Mar. Biol. **75**: 169-177.

OMORI, M. 1980. Feeding habit of yearling red sea bream (*Pagrus major*) in Yuya Bay. Bull. Seikai Reg. Fish. Res. Lab. (54): 93-109. (In Japanese with English summary)

TAKEUCHI, I., R. KUWABARA, R. HIRANO and H. YAMAKAWA 1987. Species compositions of the Caprellidea (Crustacea: Amphipoda) on the *Sargassum* zone of the Pacific coast of Japan. Bull. Mar. Sci. **41:** 253-267.

TAKEUCHI, I., H. YAMAKAWA and M. FUJIWARA (MS). The Caprellidea (Crustacea: Amphipoda) on the green alga *Cladophora* *wrightiana* HARVEY; the influence of wave exposure on species composition. (Submitted to La mer)

TERAWAKI, T. 1986. Growth and maturation of *Sargassum horneri* in Odawa Bay, Miura Peninsula. Suisanzoshoku [The Aquiculture] **33**: 177-181. (In Japanese)

TERAWAKI, T., K. NOZAWA and I. SHINMURA 1983a. Studies on morphogenesis in the early stages of *Sargassum* (Phaeophyceae, Fucales). II. *Sargassum patens*. Jap. J. Phycol. **31**: 38-43. (In Japanese with English summary)

TERAWAKI, T., K. NOZAWA, and I. SHINMURA 1983b. Studies on morphogenesis in the early stages of *Sargassum* (Phaeophyceae, Fucales). III. *Sargassum horneri*. Jap. J. Phycol. **31**: 97-101. (In Japanese with English summary)

マクサ上のワレカラ類，特にオカダワレカラの密度の周年変動

竹内一郎・山川　紘・藤原正夢

要旨: 千葉県天津小湊町地先のガラモ場にて、真多年生海藻であるマクサに棲息するワレカラ類の種組成および密度の周年変動を調査した。オカダワレカラは，一年中，全個体の67%以上を占める優占種であり，密度は5月から8月に特に高く他の季節より10倍以上高い値を示した。成熟個体がほぼ一年中採集されたことから，繁殖期が周年にわたるものと推察された。従来のガラモ場のワレカラ類の研究によると，一年生あるいは茎部多年生海藻であるホンダワラ類の上では，ホソワレカラなどの出現は秋から初夏に限られることが報告されている。これらのことから，海藻の生活形がワレカラ類の出現に影響を及ぼすと考えられる。また，オカダワレカラの分布に関する知見を整理すると，本種の棲息域は外洋に面した岩礁域の波浪の影響の少ないところに限られるのではないかと推察される。

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Seasonal changes of the Secchi disc depth and suspended solid at six stations along the main channel of the High Dam Lake, Egypt*

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MOHAMED Shehata Mohamed** and Yusho ARUGA***

Abstract: Seasonal changes of the Secchi disc depth, suspended solid, chlorophyll *a*, ignition loss and particulate organic matter were investigated at six stations (Stns. 1-6) along the main channel of the High Dam Lake in Egypt during the period from September 1986 to December 1988. Water samples were collected from the surface and 2 m layer at each station and analyzed. Patterns of seasonal changes of the parameters and the ratios of chlorophyll *a* to suspended solid and to particulate organic matter were similar mostly among Stns. 1-3 in the northern part and among Stns. 4-6 in the southern part of the lake. The Secchi disc depth was significantly correlated with suspended solid in a hyperbolic manner when the two parameters were plotted on linear scales. It is shown that both the ratios of chlorophyll *a* to suspended solid and to particulate organic matter are regionally and seasonally quite variable.

1. Introduction

The High Dam Lake is one of the largest artificial lakes in Africa. It was filled in 1960 after the construction of Aswan High Dam (ENTZ, 1974). In order to know the environmental conditions of the High Dam Lake, the Fishery Management Center (FMC) of the High Dam Lake Development Authority, Egypt, set up stations in the main channel and in Khor El Ramla in 1982, and has been conducting monthly field surveys. The distributions of chlorophyll *a* in Khor El Ramla and adjacent water in the main channel were partly reported in a previous paper (OLFAT *et al*., 1987). The results obtained in the main channel were reported by OLFAT and ARUGA (1988). In these reports the relationships between chlorophyll *a* and Secchi disc depth were presented with rather scattered data, suggesting that the proportion of chlorophyll *a* in suspended solid might be variable presumably according to the seasons and regions of the lake.

The present paper describes the seasonal changes of the Secchi disc depth and suspended solid at six stations along the main channel of the High Dam Lake in relation to chlorophyll *a* concentration and ignition loss, mainly focusing on the relationship between the Secchi disc depth and the suspended solid.

2. Material and methods

Water samples were collected from the surface and 2 m depth with a Van Dorn type water sampler at six stations (Stns. 1-6) from September 1986 to December 1988 (Fig. 1). Each water sample was filtered through a glass fiber filter (Whatman GF/C, 47 mm) which was precombusted at 450℃ for 3 hrs in a Muffle furnace and weighed, and the filter with suspended solid on it was weighed after drying overnight (or for 24 hrs) in a drying oven at 85℃. The amount of suspended solid (SS) was determined as the difference of dry weights before and after filtration of water sample. The filter was ignited again in a Muffle furnance at 450℃ for 3 hrs and weighed after cooling, and the percent decrease of dry weight was regarded as the ignition loss

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(IL). The amount of particulate organic matter (POM) was calculated by multiplying SS with IL.

The transparency of water was measured with a Secchi disc (30 cm in diameter) at each station. The chlorophyll *a* concentration was determined in the same way as described in previous papers (OLFAT *el al.*, 1987; OLFAT and ARUGA, 1988).

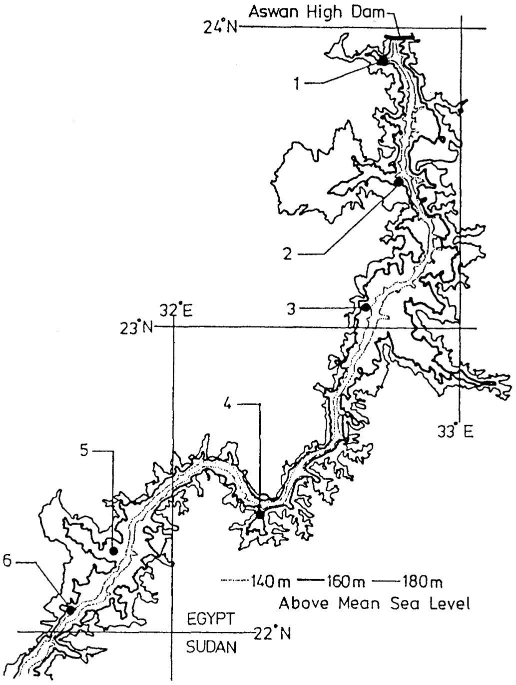

Fig. 1. Map of the High Dam Lake showing the locations of stations (1-6).

3. Results

The Secchi disc depth was highest, 5.7 m, in February 1987 at Stn. 4 and lowest, 0.2 m, in September 1988 at Stn. 6. Seasonal changes of the Secchi disc depth at Stns. 1-6 are illustrated in Fig. 2. In average, the Secchi disc depth was highest in February and lowest in August. It is noticeable that differences of the readings at six stations were small from April to June but large from August to March. Among the six stations, the Secchi disc depth was mostly lowest at Stn. 6, whereas at Stn. 1 it was highest except in January-March 1987 and February 1988. This suggests the decrease of suspended solid with flowing water along the main channel. Stns. 1 and 2 showed similar seasonal changes of the Secchi disc depth, and Stns. 5 and 6 also showed similar changes. Stn. 3 showed quite similar changes to the average of the six stations. Seasonal pattern at Stn. 4 was different from those at other stations in having big differences between the maximum and the minimum values.

Seasonal changes of the amount of suspended solid in the surface water and 2 m layer at Stns. 1-6 are illustrated in Fig. 3. The level of suspended solid was generally higher (1.0 - 59.0 g/m^3) at Stns. 4-6 in the southern part and lower (0.5 - 10.0 g/m^3) at Stns. 1-3 in the northern part of the lake. The patterns of seasonal changes of suspended solid were similar among Stns. 1-3 and among Stns. 4-6, but the patterns at the latter stations were

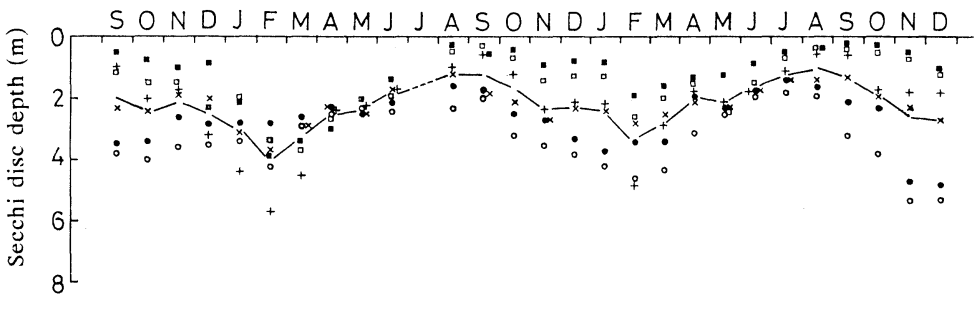

Fig. 2. Seasonal changes of the Secchi disc depth (Ds) at Stns.1-6 in the main channel of the High Dam Lake. The line is for averages of the six stations. ○, Stn.1; ●, Stn.2; ×, Stn.3; +, Stn. 4; □, Stn.5; ■, Stn.6.

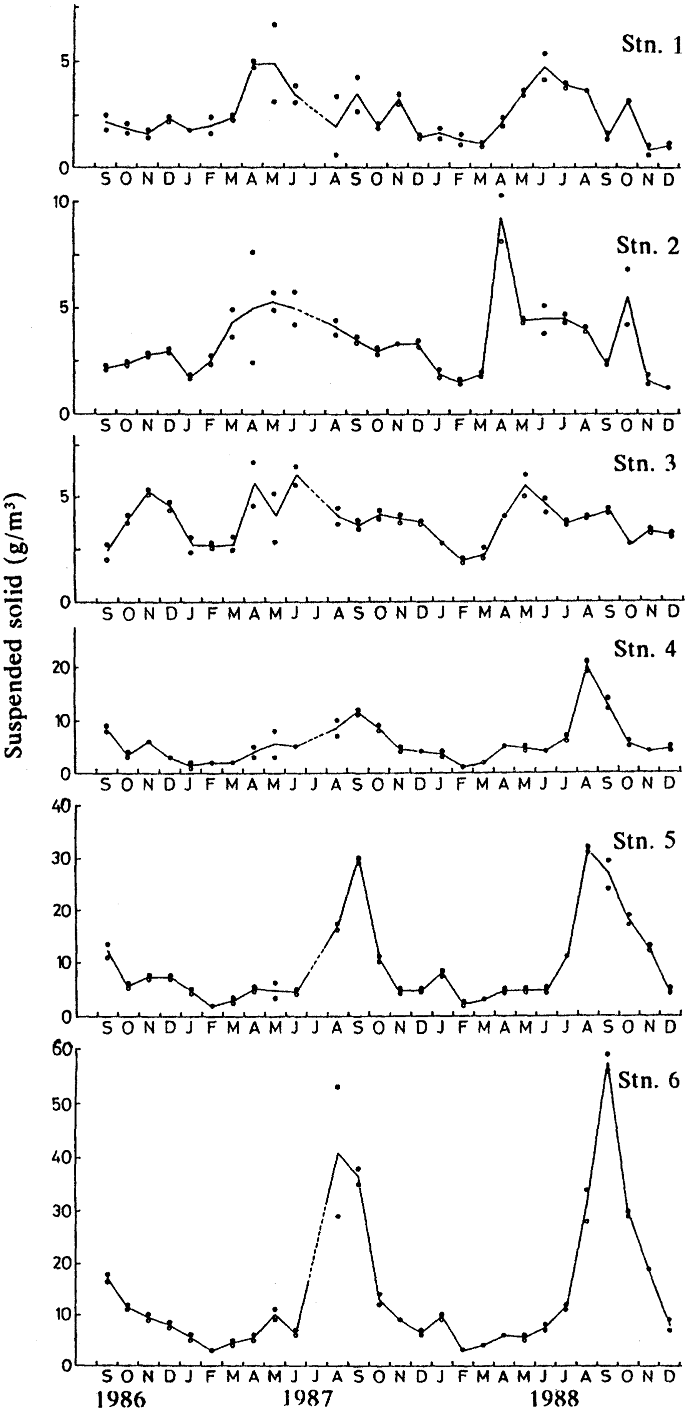

Fig. 3. Seasonal changes of the suspended solid at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

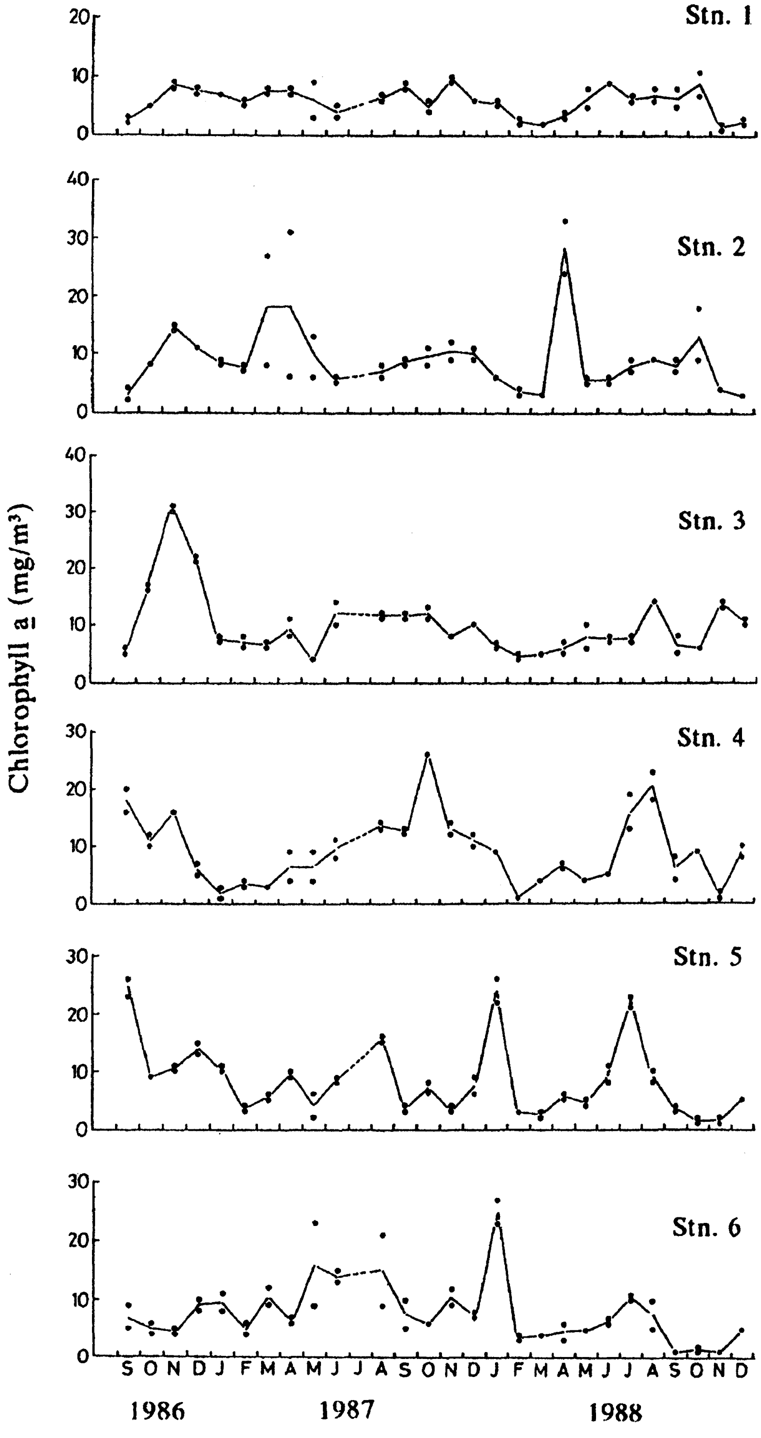

Fig. 4. Seasonal changes of the chlorophyll *a* at Stns.1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

clearly different from those at the former stations. The range of variations was quite big at Stns. 4-6 as compared with that at Stns. 1-3. Rapid increases in suspended solid were observed in April and May at Stns. 1-3 in 1987 and 1988, whereas at Stns. 4-6 rapid increases were observed in August and September in 1987 and 1988. The suspended solid was clearly high during the flood season (August-October) at Stns. 4-6.

Figure 4 illustrates seasonal changes of chlorophyll *a* concentration in the surface water and 2 m layer at Stns. 1-6. Average chlorophyll *a* concentrations were slightly higher at Stns. 4-6 (1-26 mg/m^3) than at Stns. 1-3 (1-21 mg/m^3), if the higher values of 28 mg/m^3 at Stn. 2 in April 1988 and 30 mg/m^3 at Stn. 3 in November 1986 were excluded. The seasonal patterns of chlorophyll *a* concentration were similar among Stns. 1-3 and among Stns. 4-6, even though the patterns at Stns. 1 and 6 were somewhat obscure as compared with those at other stations. The patterns at Stns. 1-3 were different from those at Stns. 4-6. The range of seasonal variations of chlorophyll *a* concentration was big at Stns. 4-6 as compared with that at Stns. 1-3. The patterns of seasonal changes of chlorophyll *a* concentration (Fig. 4) were different from those of the suspended solid (Fig. 3) at each station, even though the corresponding peaks were sometimes observed.

Figure 5 shows seasonal changes of the ignition loss of suspended solid in the surface water and 2 m layer at Stns. 1-6. The ignition loss was generally higher (25-98%) at Stns. 1-3 and lower (6-92%) at Stns. 4-6. The patterns of seasonal changes of ignition loss were similar among Stns. 1-3 and among Stns. 4-6. However, the patterns at the latter stations were clearly different from those at the former stations. The pattern at Stns. 4-6 were characterized by the lower levels of ignition loss mainly in 1988. Variations in ignition loss were big at Stns. 1-3 as compared with those at Stns. 4-6. Rapid increases in ignition loss were observed in August and September at Stns. 1-3 in 1987 and 1988, whereas at Stns. 4-6 rapid decreases were observed in the same period in 1987 and 1988. These differences could be due to the differences of variations in the proportion of inorganic suspended solid to the particulate organic matter or to the total suspended solid in the lake water. The patterns of seasonal changes of the ignition loss (Fig. 5) were quite different from those of the suspended solid (Fig. 3). This suggests that there had been big seasonal variations in the proportion of inorganic suspended solid to the total suspended solid or to the particulate organic matter.

Seasonal changes of the amount of particulate organic matter in the surface water and 2 m layer at Stns. 1-6 are illustrated in Fig. 6. The levels of particulate organic matter at Stns. 1 and 3 were comparatively low as compared with those at other stations. The average amount of particulate organic matter ranged from 0.4 to 7.5 g/m^3. Similar seasonal patterns were observed with the maximum in July-September and the minimum in December-February at Stns. 4-6. The seasonal patterns were similar at Stns. 1-3 if the two sharp peaks at Stn. 2 in April 1987 and 1988 were excluded. The range of variation was quite big at Stns. 4-6 as compared with that at Stns. 1-3. Peaks of particulate organic matter appeared a little earlier at Stns. 1-3 (April-July) than at Stns. 4-6 (July-August). The seasonal patterns of particulate organic matter (Fig. 6) were similar to those of suspended solid (Fig. 3) except that at Stn. 6.

Figure 7 shows seasonal variations of the percentage of chlorophyll *a* in suspended solid in the surface water and 2 m layer at Stns. 1-6. The average percentage of chlorophyll *a* was higher at Stns. 1-3 (0.1-0.6%) than at Stns. 4-6 (0.01-0.3%). The patterns of seasonal changes of the percent chlorophyll *a* in suspended solid were similar among Stns. 1-3 with higher values during November-January and lower values during May-July, and between Stns. 5 and 6 with higher values in January or February and lower values in September and October. The seasonal patterns at the former stations were clearly different from those at the latter stations. The patterns at Stns. 4-6 were characterized

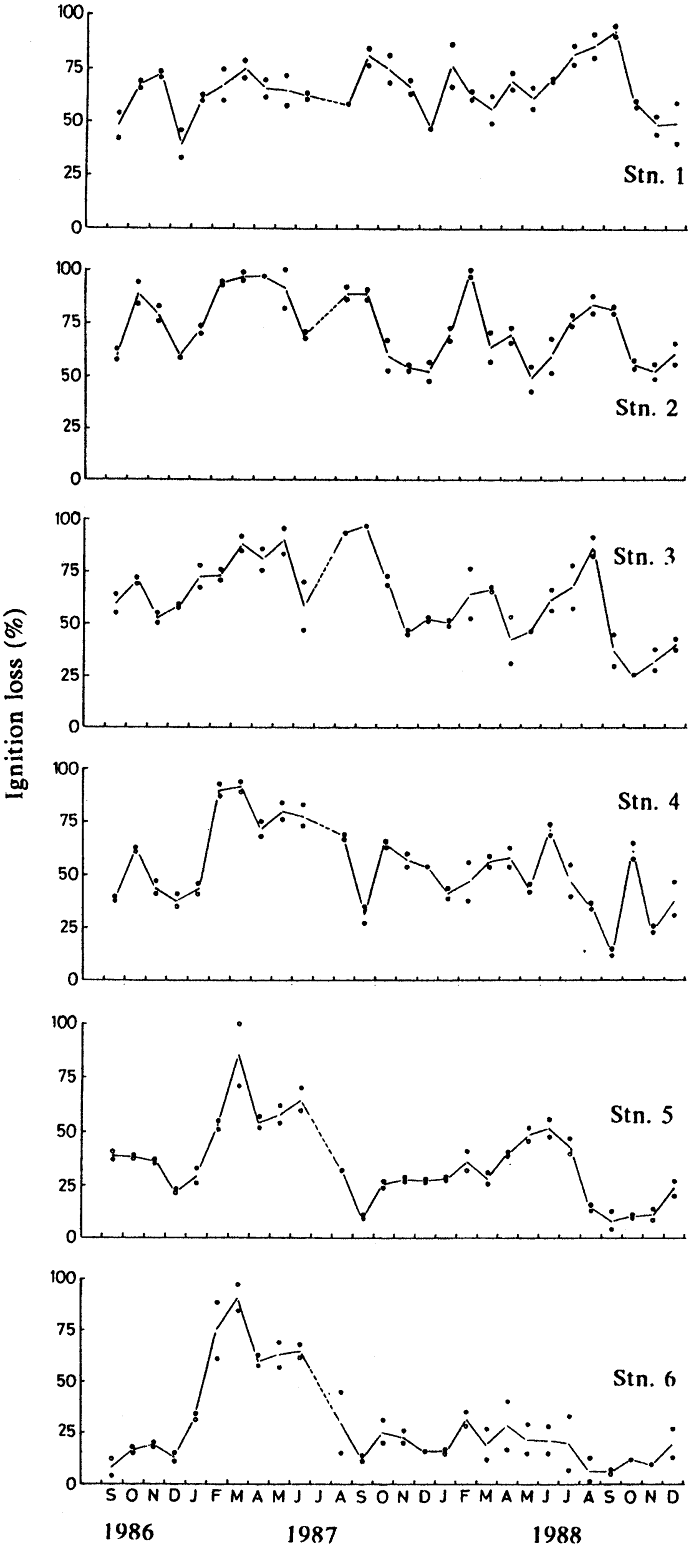

Fig. 5. Seasonal changes of the ignition loss of suspended solid at Stns.1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

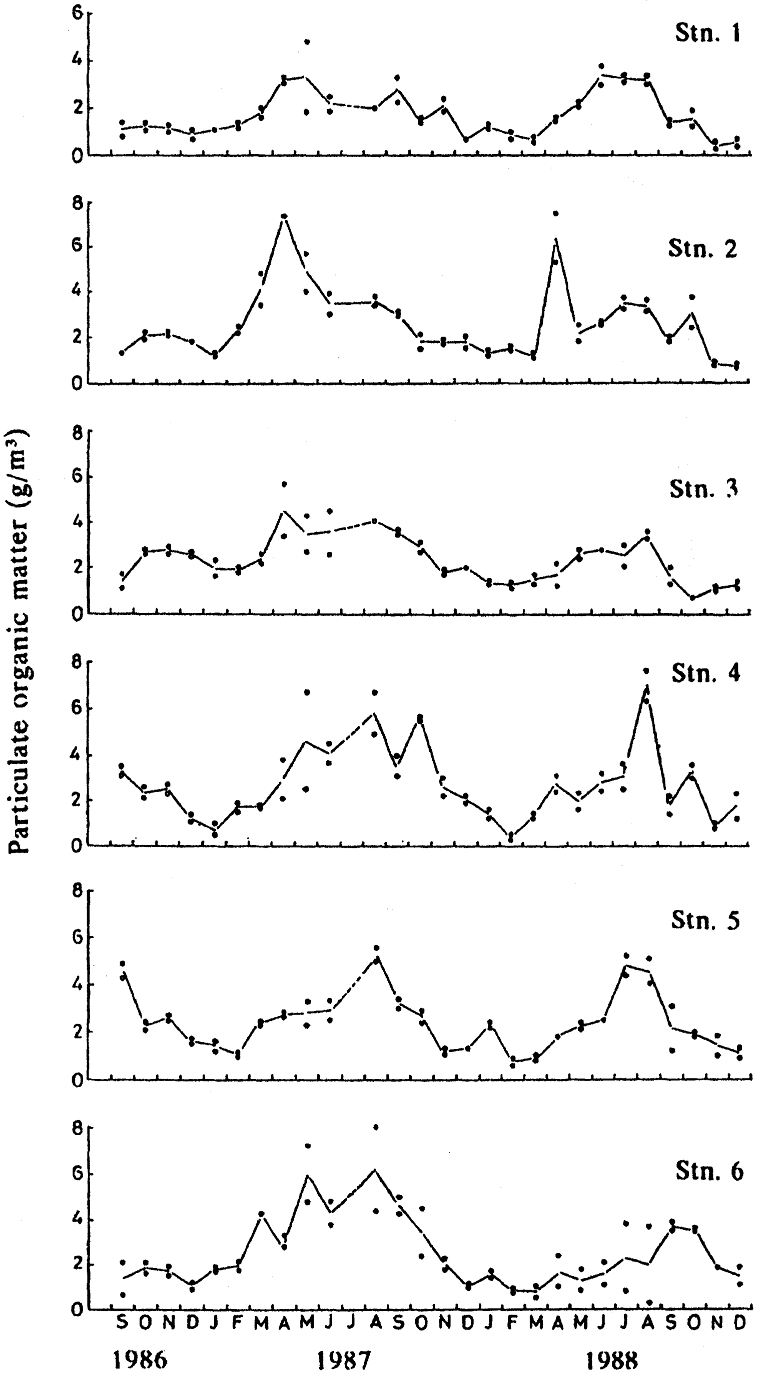

Fig. 6. Seasonal changes of the particulate organic matter at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

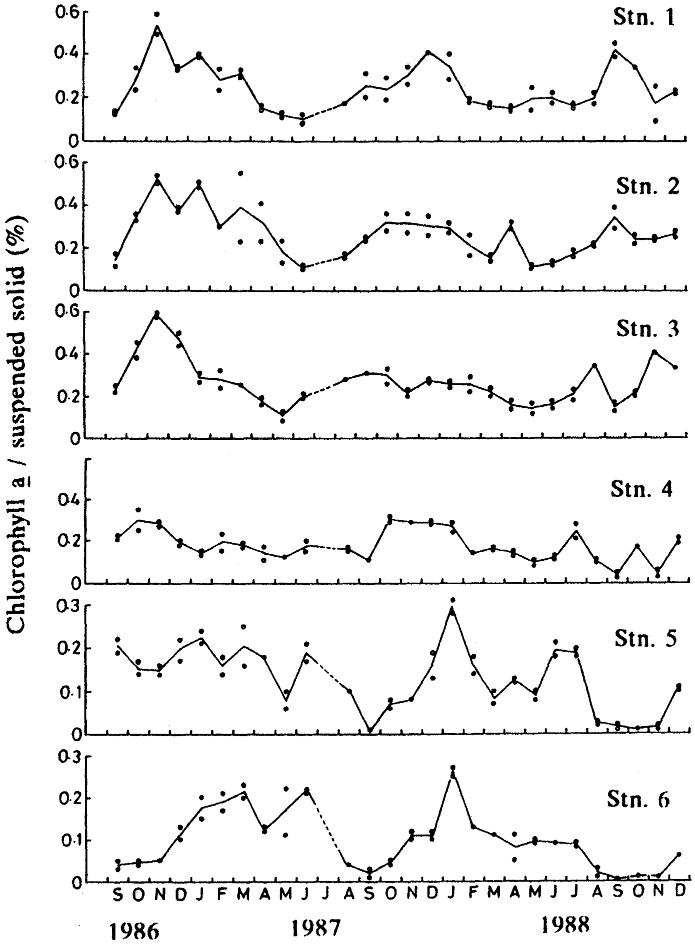

Fig. 7. Seasonal changes of the ratio of chlorophyll *a* to suspended solid at Stns. 1-6 in the main channel of the High Dam Lake. Lines are for averages of the surface (○) and 2 m (●) samples.

by frequent changes with lower levels especially in 1988.

Relationships were investigated between the chlorophyll *a* concentration and the particulate organic matter for the surface water and 2 m layer separately (Fig. 8). For both cases, there was positive correlation with considerably scattered data points between the two parameters, and no significant difference was observed between the two cases.

Figure 9 illustrates the relationship between the Secchi disc depth and the amount of suspended solid for all the data of suspended solid in the surface water and 2 m layer from September 1986 to December 1988 at Stns. 1-6. A clear hyperbolic relationship was obtained on a normal diagram and an exponential relationship on a semilogarithmic diagram. The results indicate that the Secchi disc depth was almost directly dependent on the amount of suspended solid in the lake water.

The relationship between chlorophyll *a* and suspended solid was examined separately for the surface water and for the 2 m layer as illustrated in Fig. 10. Positive correlations can be seen between the two parameters, however the data points were scattered very much. About 90% of the data were in the ranges of 1-30 mg/m^3 in chlorophyll *a* and 1-

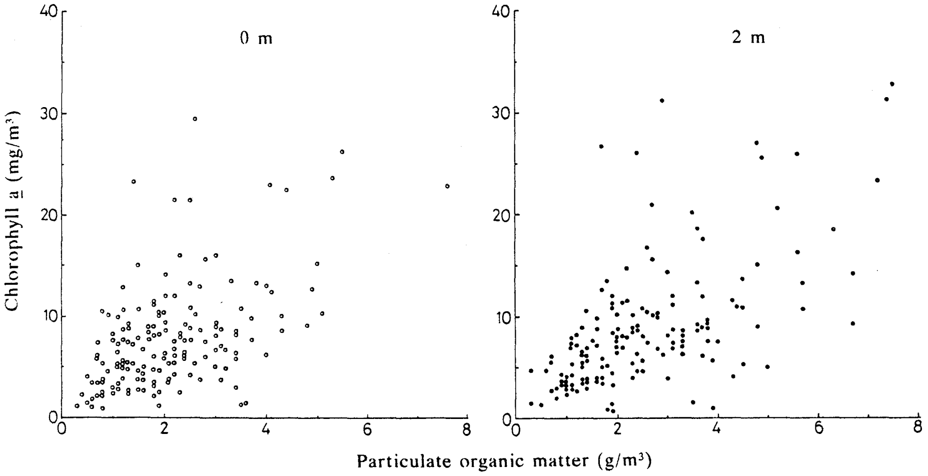

Fig. 8. Relationships between the chlorophyll *a* and the particulate organic matter at Stns. 1-6 in the main channel of the High Dam Lake.

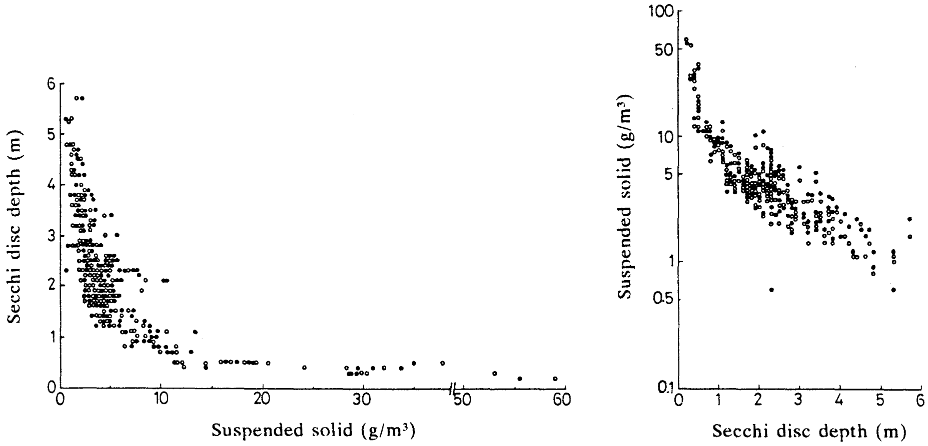

Fig. 9. Relationships of the Secchi disc depth to the suspended solid at Stns. 1-6 in the main channel of the High Dam Lake. ○, 0 m; ●, 2 m.

15 g/m^3 in suspended solid. There is no significant difference between the relationships in the two layers.

4. Discussion

The seasonal patterns of the Secchi disc depth were similar to those previously reported (OLFAT *et al.*, 1987; OLFAT and ARUGA, 1988) with higher values during the low temperature period and with lower values during the high temperature period. There seems to be a tendency for the Secchi disc depth to be lower in the southern part and higher in the northern part of the lake, which may be correlated with the decrease of suspended solid with water flow along the main channel (Fig. 3).

The levels of suspended solid were generally high during the flood season at Stns. 4-6 in the southern part of the lake. The seasonal patterns of suspended solid were quite similar with a very high peak in August or September at Stns. 5 and 6, and the peaks became lower at Stn. 4. On the other hand,

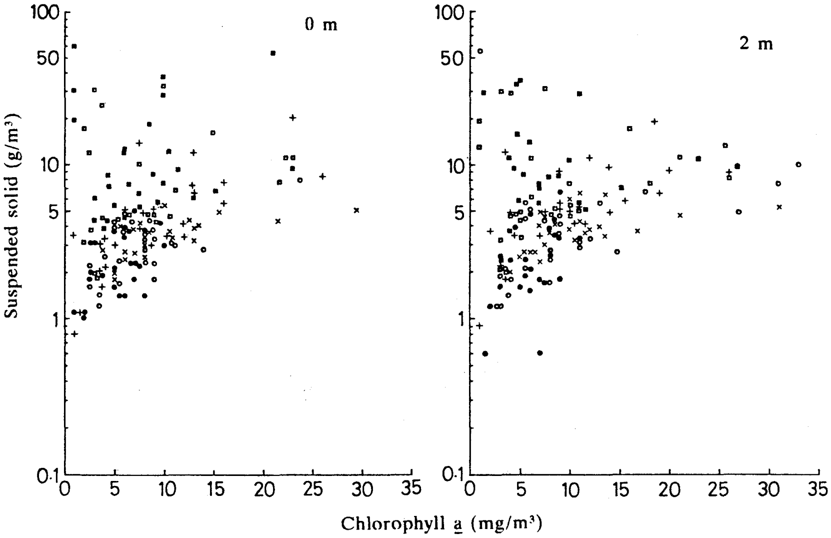

Fig. 10. Relationships between the suspended solid and the chlorophyll *a* at Stns.1-6 in the main channel of the High Dam Lake. ○, Stn.1; ●, Stn.2; ×, Stn.3; +, Stn.4; □, Stn.5; ■, Stn.6.

at Stns. 1-3 the seasonal patterns of suspended solid were quite different from those at Stns. 4-6 (Fig. 3) possibly due to changes in the composition of suspended solid, e. g. the ratio of particulate organic matter to particulate inorganic matter.

In the present investigation a similar trend was obtained in the relationship between the Secchi disc depth and the suspended solid as reported in previous papers (OLFAT *et al.*, 1987; OLFAT and ARUGA, 1988) between the Secchi disc depth and the chlorophyll *a* concentration, in the latter case the data points being much dispersed. This suggests that the Secchi disc depth was more directly dependent on the amount of suspended solid in the lake water.

According to HURST (1957) about 100 million tons of suspended sediments, composed of 30% fine sand, 40% silt and 30% clay, are carried annually with the Nile water on entering Egypt. The quantities of these sediments greatly increase at the beginning of the Nile flood. ELSTER and VOLLENWEIDER (1961) pointed out that the average value of the suspended matter in the Nile at the Egyptian borders during the flood period (August-October) amounted to 1.6 kg/m³. However, after construction of the Aswan High Dam and creation of the High Dam Lake these features were basically changed. In this respect, ENTZ (1980) mentioned that suspended material in Lake Nasser (High Dam Lake) does not exceed a few milligrams per litre and that is mostly organic matter of planktonic origin. This means that the main bulk of suspended clay was sedimented in Lake Nubia. According to the High Dam and Aswan Dam Authority (personal communication) no clay reached the Egyptian water only with high turbidity in the southern part of the lake. EL-OTIFY (1985) reported that the total suspended matter fluctuated between a minimum of 10 mg/*l* and a maximum of 132 mg/*l*, and a gradual increase in total suspended matter was recorded along the main body of the High Dam Lake from north to south in autumn 1982 and summer 1983. The present results for suspended solid are in agreement with EL-OTIFY's (1985) range of fluctuation.

It should be noted that Stns.. 1-3 showed similar patterns of seasonal changes in suspended solid, chlorophyll *a*, ignition loss, particulate organic matter and the ratios of chlorophyll *a* to suspended solid and to particulate organic matter, and Stns. 4-6 showed other similar patterns of seasonal changes in these parameters, even though sometimes Stn. 4 had seasonal patterns somewhat different from Stns. 5 and 6. It is clearly shown that both the ratio of chlorophyll *a* to suspended solid and the raito of chlorophyll *a* to particulate organic matter are quite variable with seasons and regions in the High Dam Lake. This suggests that particulate organic matter is composed of phytoplankton and other variable organic materials, or at least the chlorophyll *a* content in a cell is quite variable, with seasons and regions, and that the total suspended solid rather than phytoplankton generally plays an important role in determining transparency of water (the Secchi disc depth) of the lake.

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References

EL-OTIFY, A. M. A. M. 1985. Studies on phytoplankton of Aswan High Dam Lake. A thesis submitted for the degree of M. Sc. in Botany. Bot. Dept., Fac. Sci., Aswan Assiut Univ. 140+ivpp.

ELSTER, H. J. and R. VOLLENWEIDER 1961. Beiträge zur Limnologie Ägyptens. Arch. Hydrobiol., **57**: 241-343. (cited in SAAD, 1980)

ENTZ, B. 1974. The morphometry of Lake Nasser and Lake Nubia. Lake Nasser Development Center Project (RPA, UNDP/SE, FAO) Working Paper No. 5. Aswan. 90pp.+ 5 figs.

ENTZ, B. A. G. 1980. Sedimentation processes in the reservoir Lake Nasser-Nubia during 1965-1974 and future aspects. *In* A. K. BISWAS (ed.): Water Supply & Management, Vol. 4. Pergamon Press, Oxford. p. 63-66.

HURST, H. E. 1957. The Nile. Constable, London. (cited in SAAD, 1980)

OLFAT A. H., T. IORIYA and Y. ARUGA 1987. The distrubution of chlorophyll *a* as an index of primary productivity of phytoplankton in Khor El Ramla of the High Dam Lake, Egypt. J. Tokyo Univ. Fish., **74**: 145-157.

OLFAT A. H. and Y. ARUGA 1988. Changes of the distribution of phytoplankton chlorophyll *a* in the main channel of the High Dam Lake, Egypt. J. Tokyo Univ. Fish., **75**: 343-352.

SAAD, M. A. H. 1980. A limnological study on Lake Nasser and the Nile in Egypt (Records of February 1970). *In* A. K. BISWAS (ed.): Water Supply & Management, Vol. 4. Pergamon Press, Oxford. p. 81-92.

ハイダム湖（エジプト）の主水路に沿う6測点における透明度と懸濁物の季節的変動

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要旨: ハイダム湖（エジプト）の主水路に沿った6測点（Stns. 1-6）で1986年9月から1988年12月まで，透明度，懸濁物，クロロフィル*a*，強熱減量，懸濁有機物を調査した。各測点で表面及び2m深から試水を採取し，分析した。各測定項目及びクロロフィル*a*／懸濁物比ならびにクロロフィル*a*／懸濁有機物比の季節的変動は，ハイダム湖北部（下流）のStn. 1-3，同南部（上流）のStn. 4-6でそれぞれよく似たパターンを示した。また，透明度は懸濁物量と極めて強い相関を示した。クロロフィル*a*／懸濁物比ならびにクロロフィル*a*／懸濁有機物比は，いずれも地域により，季節により著しく変動することが明らかにされた。

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Société franco-japonaise d'océanographie, Tokyo

別府湾を含む伊予灘および豊後水道海域における海況特性の解析*

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Characterization of the environment in the Beppu Bay, Iyo Nada and Bungo Channel*

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Abstract: Environmental characteristics of the sea area around Oita Prefecture were investigated by employing the monthly observational data (1965-1988) at 54 stations in Beppu Bay, Iyo Nada and Bungo Channel. Analysis of the horizontal and vertical distributions of water temperature and salinity revealed that the sea area was subdivided into several small areas. The characteristic of the Seto Inland Sea was different from that of the Bungo Channel. There was the isolated mixing zone in the northern and southern parts of the Hayasui Strait where water temperature and salinity were uniform by the strong tidal currents, and the tidal fronts were observed. Beppu Bay seemed to be semiclosed area, which was characterized by large seasonal variations in water temperature and salinity. MEM spectra emerged dominant periods of one year and 2－4 years in water temperature and in salinity. These periods can be related to those of atmospheric temperature and precipitation, respectively. The characteristics of the Seto Inland Sea appeared to depend on the climate of the area. The Kuroshio branch strongly affected the characteristics of the Bungo Channel.

1．緒　言

海洋が環境に及ぼす影響は非常に大きなものであり，わずか2～3℃の海水温の変化が全地球的な異常気象を引き起こすことさえある。このような地球規模の海洋と大気の相互作用ばかりでなく，小さな内湾や沿岸における環境も，四方を海に囲まれた日本にとっては重要な研究対象である。たとえば，瀬戸内海は我が国最大の内海であり，豊後水道や紀伊水道などのわずかな部分で太平洋とつながっているため，これらの水道付近の海況について研究することは，瀬戸内海の特性を把握する上でも役にたつものと考えられる。

大分県は，豊予海峡を境にしてその北側が瀬戸内海に，南側は豊後水道に面しており，豊後水道はさらに日本の南西海域に接している。また，瀬戸内海からは豊後水道へ恒流として内海系冷水が南下している。そのため，この海域の海況はきわめて複雑であり，漁況に与える影響も小さくない。特に大分県沿岸に来遊するイワシ，アジ，サバ類は，主として春から夏にかけて北上し，秋から冬にかけては成魚が南下する傾向にあり，この付近の海況について明らかにすることは漁業にとっても大きく貢献できるものと思われる。これらの海域の個々の特性については，既に柳ら(YANAGI，1980，1983; 柳・大庭，1985; YANAGI and KOIKE，1987)の報告があるが，広範囲にわたる総括的な報告はあまりなされていない。

以上のことを考慮しながら，主に統計的な手法で，伊予灘，別府湾および豊後水道の海況特性の解析を試みた。

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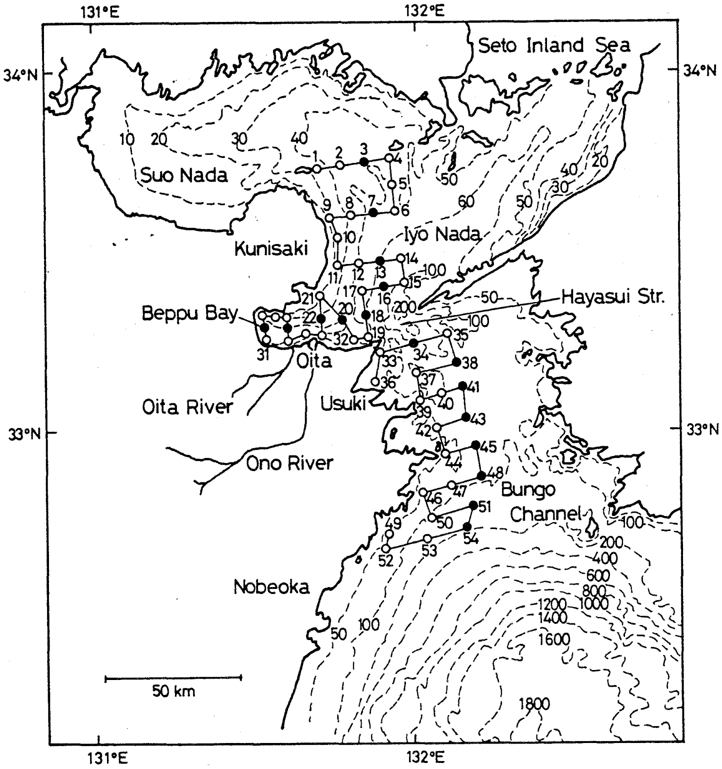

Fig. 1.　Observation stations by Oita Prefectural Fisheries Experimental Station. Broken lines represent depth in meters.

2．データおよび解析方法

（1）データ

大分県水産試験場（1965-1988）は，毎月1回伊予灘，別府湾および豊後水道の54定点を選んで海洋観測を行っている。これらの観測点は，海底地形や潮流を考慮して選定されている。Fig.1に観測点（Stn. 1－54）を示した。1965年4月から1988年3月までの23年間の各観測点における水温（0, 5, 10, 20, 30, 50, 75m深），塩分（0, 5, 10, 20, 30, 50, 75m深），天候，気温および瀬戸内海側におけるDO, COD, 窒素，リンなどの栄養塩類についてデータベースを構築し，解析に用いた。

また，大分地方気象台（1965-1988）が毎日観測している気温および降水量データ，さらに海上保安庁水路部（1965-1988）が年間24回観測を行っている黒潮本流の水温データも同様に処理した。

（2）T-S解析

水塊分布を把握するのに有効なT-S（水温－塩分）ダイアグラムを作成した。まず，各観測点ごとに海面，5, 10, 20, 30, 50, および75m深における水温と塩分の23年間のデータを月別に平均した。得られた各観測点における全水深の値を月別にグラフ上にプロットした。また，海面における全観測点の値を月別にプロットした。水深10, 20, 30および50m深における値についても同様に処理した。

（3）水温および塩分の鉛直分布

鉛直方向の水塊分布より海況特性を検討するために，伊予灘北端から速吸瀬戸を通り豊後水道南端まで南下する線（縦断線と呼ぶ）上の海域を考え，月別平均水温および月別平均塩分から，水温および塩分の鉛直分布図を作成した。選ばれた観測点は，伊予灘のStn. 3, 7, 13, 16, 豊後水道のStn.34, 38, 41, 43, 45, 48, 51および54である。同様に，別府湾のStn.18, 20, 22, 26および30を選び，別府湾についても考察した。それぞれの観測点をFig.1に黒丸で示した。

（4）スペクトル解析

各観測点の水温および塩分データに欠測があるので，その欠測月の前後数か月にn次補間多項式を当てはめて補間し（Aitken-Neville法），サンプル間隔1か月の時

系列データとした。スペクトルの計算にはMEMを用い，ARモデルの次数は，最大モデル次数を(サンプル数)／3とし，赤池の方法（南，1986）によって決定した。また，12か月周期を消去するために $1-2\cos(2\pi 3/12)B+B^2$ なる調和フィルター（岩井ら，1980）を用いた。また，水温および塩分測定期間に相当する大分市の毎日の平均気温および降水量についても，MEMスペクトルを計算した。さらに，海上保安庁水路部より得た黒潮本流の水温観測データについても，MEMスペクトルを計算した。黒潮水温データは，豊後水道に近い宮崎県都井岬沖および高知県足摺岬沖におけるものを選んだ。

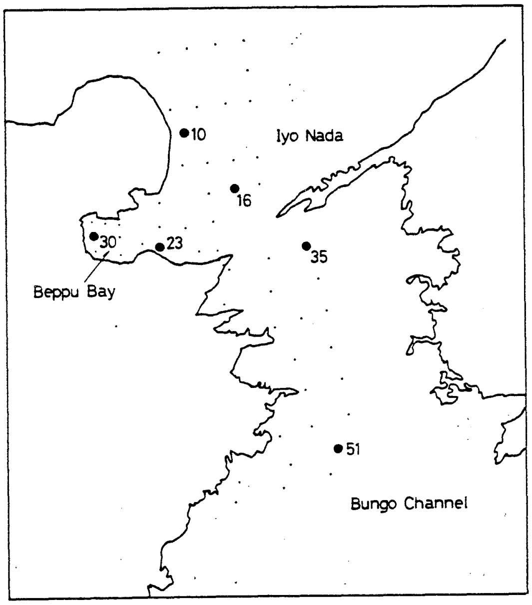

Fig. 2. Representative observation stations of sea area classified with water temperature-salinity diagrams.

3．結果と考察

（1）データ

観測データは，毎月ほぼ10日前後に得られたものであり，水温は1965年から，塩分は1969年からのものであった。また，各観測点の海面における平均欠測数は水温で21個（最大35個，最小7個），塩分で21個（最大38個，最小11個）あった。ただし，水深が増すにつれて欠測数は増加した。

（2）T-S解析

54の観測点すべてについて，各月ごとに（すなわち

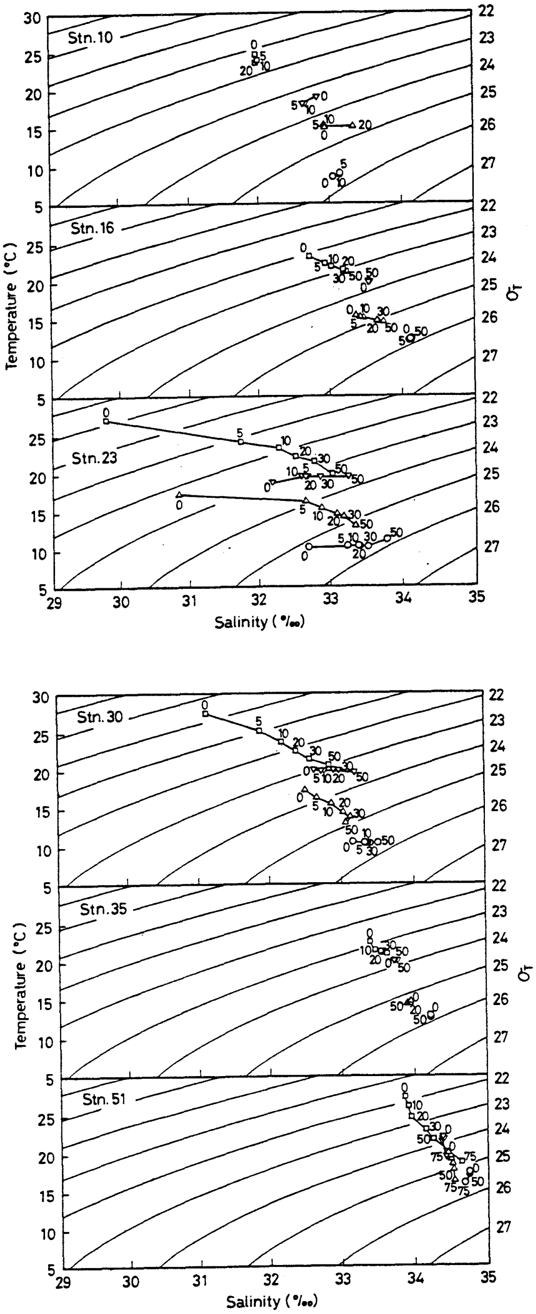

Fig. 3. Water temperature-salinity diagrams of representative observation stations. ○, February; △, May; □, August; and ▽, November. Numerals denote depth in meters.

54×12＝648個の）海面から最深観測深度にいたるまでのT-Sダイアグラムを作成した。全般的に，春季から夏季にかけて海面から最深観測深度までの変化が大きく，秋季から冬季にかけてはそれが小さかった。つまり，春季から夏季にかけては，成層が発達していることがわかった。ただし，瀬戸内海は塩分の変化の大きい成層であるのに対し，豊後水道は等密度線に対し垂直に変化している成層であった。また，豊後水道におけるStn.33-39では，年間を通じて非常に変動が小さかった。

つぎに，得られたT-Sダイアグラムを類似の季節変動をする海域ごとに分類し，それぞれの中から代表点を選んだ(Fig.2)。選ばれた観測点のT-Sダイアグラムのうち，2月，5月，8月および11月をそれぞれ冬季，春季，夏季，および秋季の代表としてFig.3に示した。また，海面におけるT-Sダイアグラムのうち2月，5月，8月および11月のものをFig.4に示した。Fig.3から，国東半島沿岸のStn.10では，冬季に著しい低温傾向を示していることがわかる。国東半島沿岸は，冬季に特有の冷水塊を形成することが知られており（YANAGI, 1980)，このことはFig.4の2月のT-Sダイアグラムにもはっきり現われている。つまり，伊予灘のStn.1, 8-11および21だけが9℃前後の独立した水塊分布を示しており，国東半島沖との水温差が著しい沿岸フロントを形成していることが予想される。これは，冬季の強い北西季節風（河村，1977）によって国東半島沿岸を周防灘系冷水塊が吹送流となって南下しているためと考えられる。この傾向は11月に国東半島北部沿岸から始まり，3月まで続いた。またFig.3から，速吸瀬戸北側に位置するStn.16では，秋季から冬季に瀬戸内海としては比較的高温高塩分を示し，夏季に期待される成層の程度も小さかった。一方，別府湾内のStn.30では，夏季に海面の低塩分と非常に安定した成層状態を示した。このように夏季の別府湾は，成層により鉛直混合がなく湾口部が湾奥部に比べて相対的に浅く停滞しやすいので，Fig.4からわかるように海面では著しく高温(25-28℃)かつ低塩分(30-32)の水塊を形成した。つまり，夏季における浅海暖水の典型である。しかしながら，Fig.5に見られるようにこの高温低塩分も海面のみであり，10，20，30mと水深が増すにつれてほぼ一定の低温高塩分に近づいて行くのがわかる。この別府湾の極端な例が，別府湾内の大野川河口付近のStn.23であり，Fig.3からわかるように，春季から夏季にかけて海面における著しい低塩分を示し，成層が発達していた。また，秋季でも塩分の差が大きかった。ここでは，梅雨および秋雨期の降雨による河川水流入増に起因する激しい塩分の変化が特徴であるが，この希釈効果はたかだか5mぐらいまでであり，日本のように水量の少ない河川に特有の現象である。Fig.6に，この解析期間と同じ期間の大分市における月別平均降水量を示した。塩分低下と降水量との関係がよく対応している。さらにFig.3より，速吸瀬戸南側のStn.35は，冬季比較的高温高塩分であり，夏季にも水温および塩分の変化が小さい．また，速吸瀬戸北側のStn.16によく似た挙動を示している。豊後水道のStn.51では，夏季に成層が発達するものの，それ以外の季節では変化が小さかった。豊後水道を南下するにつれて，高温高塩分で変化の小さいT-Sダイアグラムが得られ，より黒潮本流の季節変動に近づいていると考えられる。

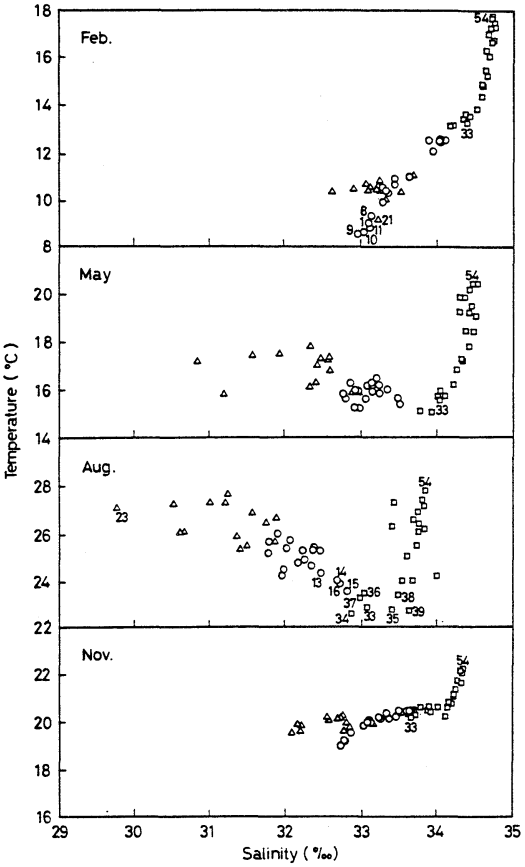

Fig. 4. Mean water temperature-salinity diagrams at sea surface from 1965 to 1988. ○, Iyo Nada; △, Beppu Bay; and □, Bungo Channel. Numerals denote station numbers.

またFig.4から，豊後水道ではいずれの季節でも，

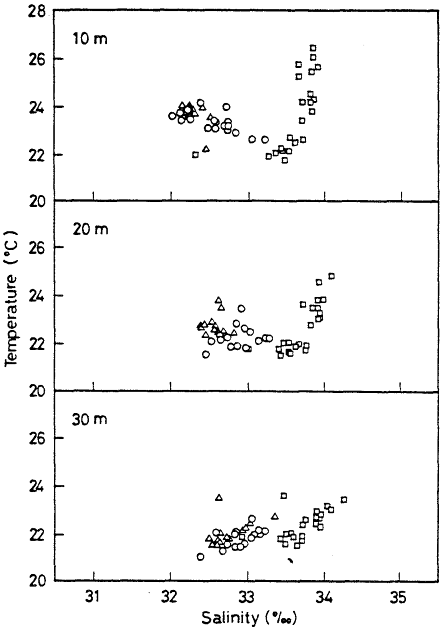

Fig. 5. Mean water temperature-salinity diagrams at subsurfaces in August. ○, Iyo Nada; △, Beppu Bay; and □, Bungo Channel.

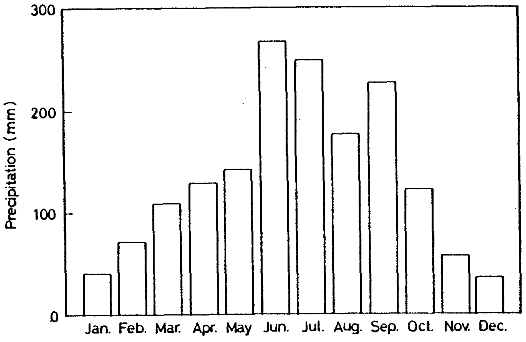

Fig. 6. Seasonal variation of mean precipitation at Oita from 1965 to 1988.

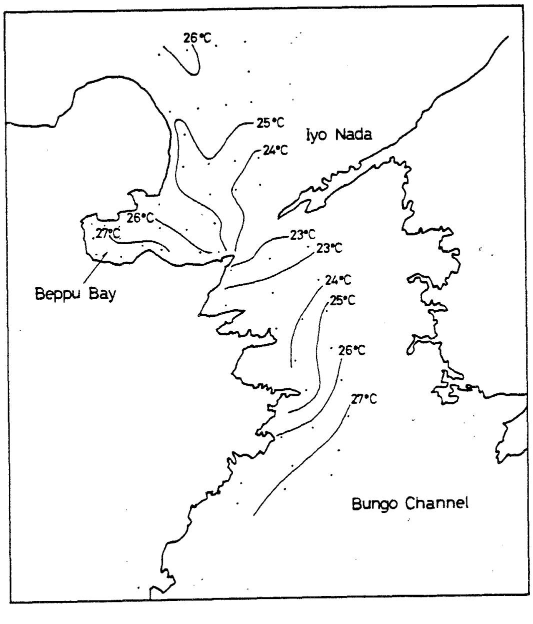

Fig. 7. Horizontal distribution of water temperature in Iyo Nada, Beppu Bay and Bungo Channel in August.

Stn.54から33へ北上するにつれて水温のみが大きく低下し，塩分の変化は小さかった。一方，伊予灘および別府湾では塩分が大きく変化しており，水温も季節ごとに特徴ある変化を示した。春季および夏季には伊予灘北部，別府湾および豊後水道南部ともに水温が高く，速吸瀬戸の南北のStn.13-16およびStn.33-39の狭い海域だけ低温になっていることがわかる。この様子をFig.7の水平分布図に示した。これは，速吸瀬戸の南北の海域以外では夏季の表面加熱によって成層してしいるのに対して，ここでは最大4.6ktにも達する1日4回の潮汐流（海上保安庁水路部，1987）による水平および鉛直方向の活発な混合により，海面から最深観測深度まで均一な水温および塩分の水塊を形成しているためと考えられる。これが，緒方ら（1985）の言う夏季における速吸瀬戸付近での冷水塊に相当しているものと考えられる。

（3）水温および塩分の鉛直分布

2月，5月，8月および11月の縦断線上の各観測点における水温および塩分の鉛直分布をFig.8およびFig.9に示した。

2月には，海面冷却による鉛直混合が起こり，海面と最深観測深度との水温差が全くない。この傾向は，豊後水道のStn.38以北で特に著しかった。また，南高北低の水温分布であり，豊後水道南部と伊予灘北部との差は約7度にも達した。塩分も水温と同様南高北低でその差は1であるが，豊後水道のStn.41以南ではほとんど差がなくなっており，ほぼ一定の34.7を示した。

4月になると気温上昇にともなって表面水温も上昇しはじめ，5月には明らかに成層し，速吸瀬戸から北にあるいは南に行くほど海面と最深観測深度の温度差が大きくなった。これに対して，速吸瀬戸付近の豊後水道のStn.34では，ほとんど差がなくなった。塩分は，2月と

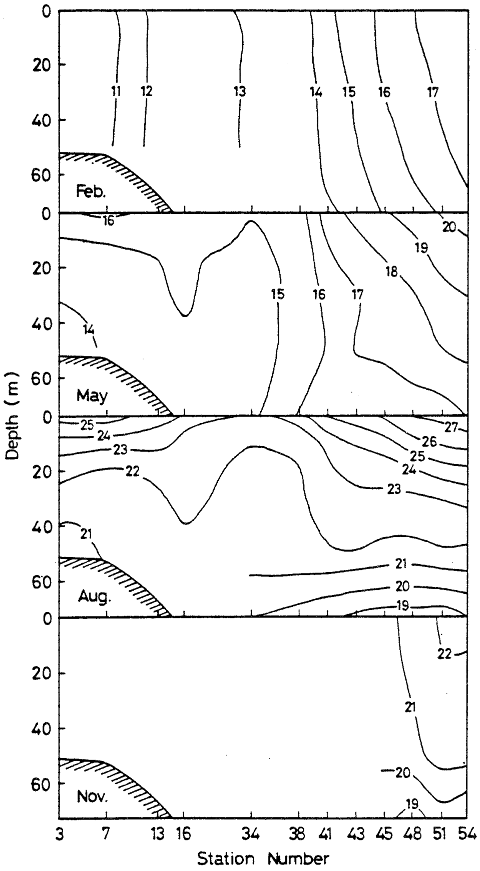

Fig. 8. Vertical distribution of water temperature in Iyo Nada and Bungo Channel.

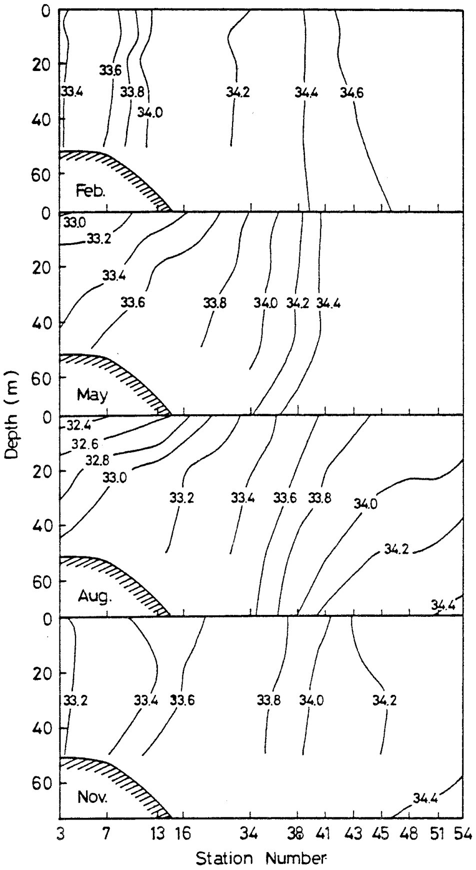

Fig. 9. Vertical distribution of salinity in Iyo Nada and Bungo Channel.

同様に豊後水道の Stn.41 以南では 34.5 と差がないものの，そこから北上するにつれて海面と最深観測深度の差が生じた。また，南高北低の塩分分布を示し，かつその差は 2 月より大きく 1.5 になっており，内海への陸水の流入量が増加しはじめることを表わしている。

8 月には，海面の水温上昇が著しく，海面と最深観測深度との温度差も非常に大きいことがわかる。海面と 50m 深の水温差は，伊予灘で 5 度，豊後水道南部で 6 度にも達した。しかしながら，豊後水道の Stn.34 では 2 度ほどしかなく，この傾向は，速吸瀬戸の北と南に隣接する伊予灘の Stn.15-17 および豊後水道の Stn.33-35 でもほとんど同じであった。塩分も同様に，豊後水道の Stn.34 ではほとんど差がなく，速吸瀬戸からはなれるにしたがって海面と最深観測深度の差が大きかった。このように，夏季には縦断線上で水温および塩分ともに速吸瀬戸付近で収束する結果が得られた。以上のことから，速吸瀬戸付近で鉛直方向の強い混合が起こっていることが明らかであるが，これは，藤原・早川（1978）の瀬戸内海の海峡部における速い潮流による鉛直混合発生と同じメカニズムと考えられる。夏季には瀬戸内海の水温に鉛直方向の大きな分布が現われるため混合の様子を明確に観察することができたが，この主な原因は潮汐流によると思われるので，強い混合は年間を通じて生じているものと推定される。

9 月には海面と最深観測深度の水温差が小さくなりはじめ，11 月になるとその温度差が全くなくなり，さらに伊予灘側と豊後水道側との間にも温度差がなくなっていることがわかる。つまり，水平方向にも鉛直方向にも水温差がない。詳細に見ると豊後水道の北部と南部で 1−2 度の水温差があるが，この差も年間を通じて最も小さい。塩分の分布は 2 月と同様に，南高北低でその差は 1 程度になっているものの，海面と最深観測深度との塩分の差

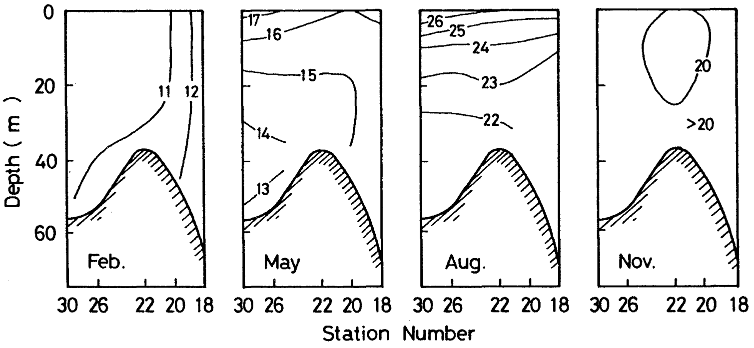

Fig. 10. Vertical distribution of water temperature in Beppu Bay.

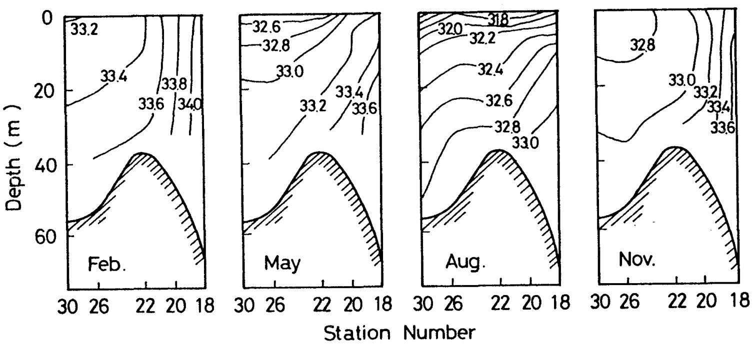

Fig. 11. Vertical distribution of salinity in Beppu Bay.

はほとんど見られなかった。これが，秋季の典型的な海況である。

以上のように，内海ほど気温と陸水の影響による水温および塩分の季節変動が大きく，一方，豊後水道ではあまり影響を受けていない。特に，豊後水道の Stn.41 以南の塩分は降水量の多い夏季を除いてほぼ 34.3-34.7 のせまい範囲に納まっていた。また，これらの図を見ると，特に冬季に伊予灘の Stn.7 と 13 との間および豊後水道の Stn.38 と 41 との間で等温線または等塩分線の間隔が狭くなっており，この部分でフロントを形成している（柳・大庭，1985）ことを示している。これは，速吸瀬戸付近の混合域の広さを表しており，速吸瀬戸の南北の混合海域の Stn.13-18 および Stn.33-39 に相当するものであろう。速吸瀬戸南側のフロントは，吉岡（1971，1984）による紀伊水道のフロントに対応するものと考えられる。

以上のような伊予灘－豊後水道で行った解析を，別府湾内でも行った。Fig.10 および Fig.11 にその結果を示した。選択された観測点は，湾中央部を東西に横断している。いずれの観測点においても最低水温を示すのは 3 月で，冬季には海面から最深観測深度までほぼ同じ水温と塩分を示した。4 月には水温上昇が始まるが，海面の方が上昇速度も大きく，成層が始まる。さらに夏季には，湾奥部に行くほど海面と最深観測深度の水温差，塩分差が大きく，湾口部には潮汐流の混合効果があると考えられる。冬季の別府湾の Stn.20 と 18 の間の等温線および等塩分線の間隔が狭く，ここにもフロントが形成されているものと考えられる。

（4）スペクトル解析

Fig.12 に，観測期間の長い代表的な観測点の水温と塩分の時系列データを示した。瀬戸内海では水温および塩分の振幅が大きく，逆に豊後水道では小さいことがわかる。また，例として Fig.13 および Fig.14 に伊予灘の Stn. 1 における海面水温および塩分の MEM スペクトルを示した。予想されたように，どちらも 1 年周期が卓越していた。しかしながら，それぞれのスペクトル強度は水温で 10^5，塩分では 10^3程度にすぎなかった。同様

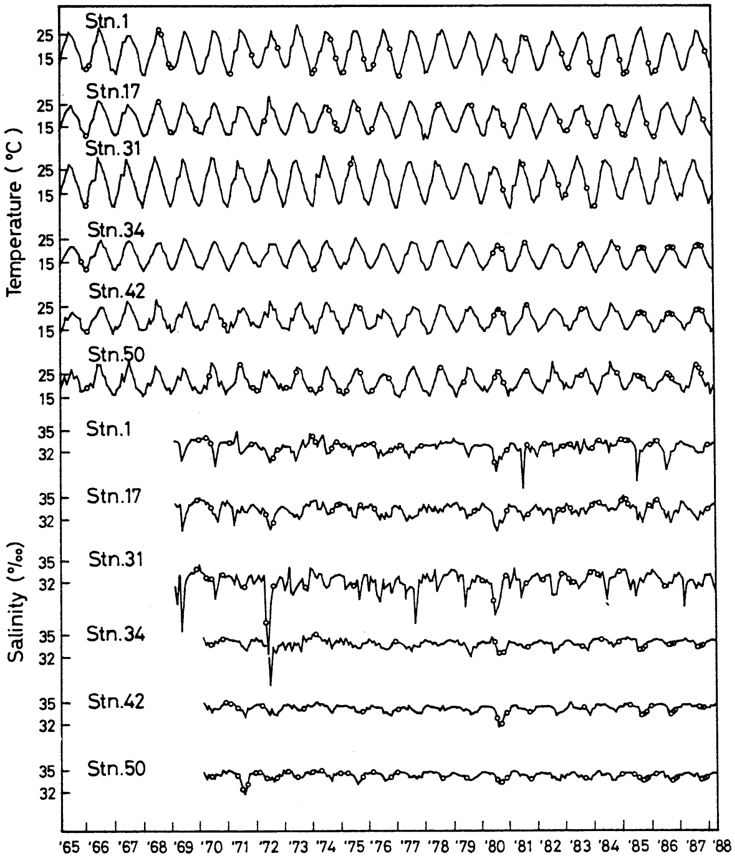

Fig. 12. Time series of sea surface water temperature and salinity at representative observation stations. Open circles denote the interpolated data.

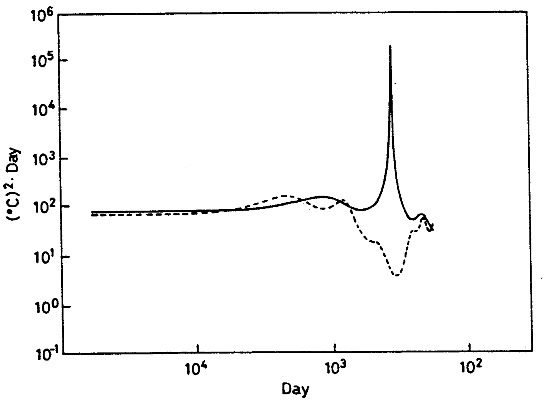

Fig. 13. MEM spectra of sea surface water temperature at Stn. 1 in Iyo Nada. Solid line represents the spectrum for the raw data and broken line for the data through the harmonic filter.

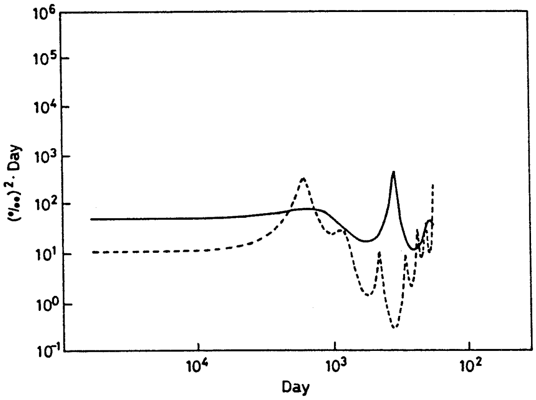

Fig. 14. MEM spectra of sea surface salinity at Stn. 1 in Iyo Nada. Solid line represents the spectrum for the raw data and broken line for the data through the harmonic filter.

Table 1. Dominant periods of MEM spectra of water temperature, salinity, atmospheric temperature and precipitation.

Station no.	Dominant period of water temperature (Year)	Dominant period of salinity (Year)
1	1.0 3.2	1.0 4.3
2	1.0 1.8 3.4	1.0 3.6
3	1.0 2.8	1.0 3.8
4	1.0 2.1*	1.0 4.7
5	1.0 2.8	1.0 4.2
6	1.0 2.7	1.0 4.0
7	1.0 2.3	1.0 3.5
8	1.0 2.2 5.5	1.0 3.5
9	1.0 3.4	— 4.7* 2.7*
10	1.0 3.2	1.0 3.8
11	1.0 3.3	1.0 3.8
12	1.0 3.6	1.0 4.0
13	1.0 4.1	1.0 3.9
14	1.0 4.7	1.0 3.5
15	1.0 3.6	1.0 4.1
16	1.0 4.6	1.0 4.1
17	1.0 4.5	1.0 4.1
18	1.0 4.0	1.0 3.5*
19	1.0 4.7 1.4	1.0 3.4*
20	1.0 4.3 1.8	1.0 5.1*
21	1.0 3.5	1.0 4.1
22	1.0 4.0 2.3	1.0 4.0
23	1.0 4.2	— 4.0*
24	1.0 2.8	1.0 3.0
25	1.0 2.4	1.0 2.7*
26	1.0 3.3	1.0 3.5
27	1.0 3.3	1.0 4.0
28	1.0 3.4	1.0 4.1
29	1.0 3.6	1.0 4.5
30	1.0 3.4	1.0 3.7
31	1.0 3.2	— 4.5* 2.7* 1.7*
32	—	—
33	1.0 3.7	1.0 2.7 1.4
34	1.0 4.8 2.5 1.3	1.0 3.5
35	1.0 5.2 1.3 2.3	1.0 6.8*
36	1.0 1.5 4.4	1.0 2.6* 6.5*
37	1.0 1.6 4.2	1.0 6.5*
38	1.0 2.0 3.6	1.0 3.0*
39	1.0 3.7 1.4	1.0 2.3*
40	1.0 3.1	1.0 3.9*
41	1.0 3.7	1.0 1.2 4.2 2.6
42	1.0 3.5*	1.0 4.1
43	1.0 3.6*	1.0
44	1.0 1.7	1.0
45	1.0 4.3 1.6	1.0 3.0
46	1.0 1.9	1.0 3.0*
47	1.0 2.8	1.0 5.4*
48	1.0 2.1	1.0 3.6 1.6
49	1.0 5.1 1.4 1.9	1.0 5.4* 2.0*
50	1.0 4.4 1.6	1.0 4.0 1.8 1.3
51	1.0 4.6	1.0 1.7 3.7
52	1.0 3.9 1.6	1.0 1.8 1.2 3.8
53	1.0 3.7 1.6	1.0 3.8*
54	1.0 3.0	1.0 2.3*
Toi	1.0 2.7*	
Ashizuri	1.0 2.6*	
Atmospheric temperature	1.0 2.8*	
Precipitation		— 3.1*

*Spectra for the data through the harmonic filter.

に、各観測点の表面水温および塩分のMEMスペクトル解析を行った。各水深の測定データからもMEMスペクトルを計算したが，海面と周期の違いは見られなかったので，海面について考察した。いずれの観測点でも1年周期が卓越していた。また，気温および黒潮水温も1年周期が卓越していた。しかし，河口付近の塩分および降水量の生データは確率過程に含まれず，スペクトルは得られなかったため，調和フィルターを通して1年以外の周期性があるかどうかを検討した。また，1年周期しかみられない観測点の水温および塩分についても同様に処理した。このようにして得られた結果をTable 1にまとめた。

水温に関しては，1年以外に国東半島沿岸のStn. 1, 9-11, 21で3.2-3.5年，速吸瀬戸北側のStn.12-20で3.6-4.7年，別府湾のStn.26-31で3.2-3.6年，別府湾河口域のStn.24と25で2.4-2.8年の周期性が見られた。これらは，先のT-S解析から明らかになった海域にほぼ一致している。一方，豊後水道では，Stn.39-43に3.1-3.7年，Stn.50-53に3.7-4.6年の周期性が見られたが，T-S解析の結果とはそれほどよい対応を示さなかった。大分市の気温には2.8年，都井岬沖および足摺岬沖の黒潮本流にそれぞれ2.7年および2.6年の周期があり，いずれも伊予灘および別府湾の水温における周期性とほぼ一致しており，互いに強い相関がある。また，塩分に関してはT-S解析とそれほどよい一致を示さなかったが，速吸瀬戸北側のStn.10-17で3.5-4.1年，別府湾のStn. 27-31で3.7-4.5年，別府湾河口域のStn.24と25で2.7-3.0年の周期性が見られ，豊後水道では2-4年の

種々の周期性が見られた。大分市の降水量については3.1年の周期があり，伊予灘および別府湾の塩分，特に別府湾の河口域の塩分における周期性とよく一致している。YANAGI (1983)は，同じ豊後水道の愛媛県側の水温および塩分のスペクトル解析により，3－5年の水温周期性と，3年の塩分の周期性を認めている。しかしながら，本研究における豊後水道の大分県側では種々の周期性が得られた。これは，秋山・柳（1989）の日向灘定点観測データの解析でも明らかにされているように，豊後水道の愛媛県側は黒潮分岐流の影響を直接受けるが，大分県側では瀬戸内海からの南下流と黒潮分岐流の影響を受けるためと考えられる。そのため，黒潮勢力の変化により2年から4年にわたる比較的幅広い周期性が観測されたものと思われる。

4．結　論

本報の検討結果により，伊予灘，別府湾および豊後水道ではその海況特性がそれぞれ異なっていることが明らかになった。特に，瀬戸内海と豊後水道では挙動が大きく異なっていた。水温および塩分の解析から，速吸瀬戸の南北の狭い海域で潮汐によると思われる強い混合が起こっていることが確認された。さらに，この混合域は，北部で国東半島沖の海域と，また南部では豊後水道南部の海域とのあいだにフロントを形成していることが明らかになった。一方では，別府湾の閉鎖性があらためて確認された。水深が浅いため，年間を通しての水温および塩分の変化の大きいことが特徴で，この閉鎖性は別府湾奥部に行くにしたがって著しかった。

水温および塩分には，1年周期以外に2－4年の弱い周期性がみられ，気温，降水量および黒潮の影響を強く受けていることがわかった。

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文　献

秋山秀樹，柳哲雄(1989):日向灘の水系分布とその季節変動．沿岸海洋研究ノート，**27**，146-157.

藤原建紀，早川典生（1978）：明石海峡における表層水の集束，発散および鉛直混合について．1978年度日本海洋学会春季大会講演要旨集，p.117-118.

岩井重久，住友恒，松岡譲（1980）：水質データの統計的解析．森北出版，東京．p.124-129.

海上保安庁水路部（1965-1988）：海洋速報．

海上保安庁水路部（1987）：豊後水道及付近潮流図．

河村武（1977）：全国地上風分布図．気象庁技術報告，(91)，1-76.

南茂夫(1986)：科学計測のための波形データ処理．CQ出版，東京．p.166-180.

緒方純俊，工藤勝宏，篠原俊夫，幡司明(1985)：NOAA/AVHRRデータによる豊後水道周辺海域における水塊特性の把握．日本リモートセンシング学会誌，**5**，5-13.

大分県水産試験場（1965-1988）：漁況海況予報事業結果報告書．

大分地方気象台（1965-1988）：気象月表．

YANAGI, T. (1980): A coastal front in the Sea of Iyo. J. Oceanogr. Soc. Japan, **35**, 253-260.

YANAGI, T. (1983): Variability of the oceanic condition in the Bungo Channel. La mer, **21**, 21-28.

柳哲雄，大庭哲哉（1985）：豊後水道のTidal Front．沿岸海洋研究ノート，**23**，19-25.

YANAGI, T. and T. KOIKE (1987): Seasonal variation in thermohaline and tidal fronts, Seto Inland Sea, Japan. Continental Shelf Res., **7**, 149-160.

吉岡洋（1971）：冬期紀伊水道のOceanic Frontについて．海と空，**46**，31-44.

吉岡洋（1984）：沿岸海域のフロント．沿岸海洋研究ノート，**21**，110-117.

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Société franco-japonaise d'océanographie, Tokyo

日本列島周辺の台風高潮パターン２例*

中 村 重 久**

Two patterns of typhoon-induced storm surges around the Japanese Islands*

Shigehisa NAKAMURA**

Abstract: Two recently observed patterns of typhoon-induced storm surges around the Japanese Islands are introduced. Meteorological anomaly of the sea level is obtained after eliminating the predicted tides out of the mareogram at each tide station for the typhoons 8506 and 8719. The meteorological anomaly is separated into two parts, i.e. baromertric and non-barometric effects. The local winds are considered in relation to a part of the non-meteorological effects, though only a qualitative notice is given. A discussion is made to know whether any hazardous storm surge is a type of the Kelvin-like waves.

1. 緒　言

台風は北太平洋西部沿岸域で高潮をひきおこし，水災害の要因のひとつである。この台風や高潮については，伊勢湾台風以来，気象庁（1961）によって予・警報に関連した問題としての調査報告が出されている。一方，DEACON and DEACON (1982) は，北海の高潮を論ずるにあたり，NOMITSU（たとえば，1934）の気圧に対する海面の応答に関心を示している。北海の高潮の数値計算（1953年1月31日－2月1日）の例もHANSEN（1956）により発表されている。また，FANDRY *et al.* (1984) は，サイクロンによって生じたKelvin型の高潮を考えた。台風高潮については，中村（NAKAMURA, 1981; 1988; 中村, 1988）の検討例がある。

本論文では，最近，日本列島に強い影響を及ぼした台風高潮の２例について，検潮記録によってとらえられたパターンを示す。これによって，台風の経路が異なるとき，台風による潮位偏差にも顕著な差異があることを示すことができる。気圧低下の効果のほかに，検潮所の位置によっては，風の効果が大きいこともある。具体的観測例によって再確認するとともに，高潮災害とKelvin型高潮との関連についても考察する。

2. 台風の経路

ここで検討の対象とする台風高潮については，中村（1988）が海面水温と関連づけて調べている。本論文では，それと別の面から検討を試みる。便宜上，２つの台風例をえらび，その台風の日本列島周辺における経路をFig.1に示した。すなわち，台風8506（実線）と台風8719（破線）である。台風8506は，九州南方洋上から紀伊半島沖を経て静岡県沿岸に上陸し北東進した。台風8719は，四国南方洋上から加古川市付近へ北上し日本海へ出た後に北東進した（cf. Fig. 2）。

3. 台風高潮の特徴

これらの台風高潮の特徴をとらえるため，気象庁所管の検潮記録を利用することとした。台風8506に関連して利用した検潮記録は，宮古，大船渡，小名浜，岡田，御前崎，尾鷲，浦神，潮岬，南部，室戸岬，土佐清水，油津である（ただし，南部は京都大学の圧力式潮位計による）。上に示した検潮所の位置を記号化し，Fig.1に示した。すなわち，それぞれMIY, OFU, ONA, OKA,

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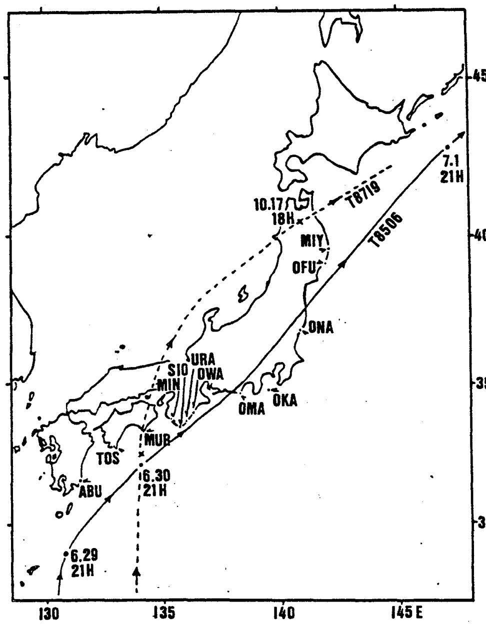

Fig. 1. The tracks of Typhoons 8506 and 8719. Solid line: the track of Typhoon 8506 from 29 June to 1 July 1985. Dotted line: the track of Typhoon 8719 from 16 to 17 October 1987. Dots: tide stations where the mareograms of Typhoon 8506 were obtained.

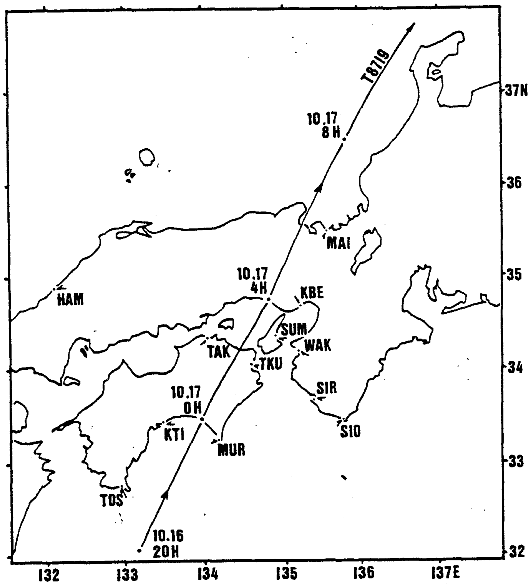

Fig. 2. The track (solid line) of Typhoon 8719 from 20h on 16 October to 8h on 17 October 1987. Dots: tide stations where the mareograms of Typhoon 8719 were obtained.

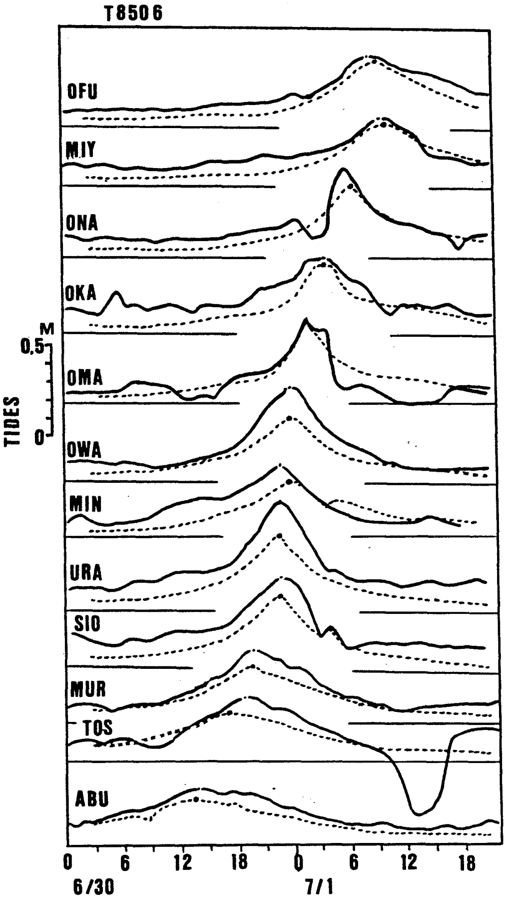

Fig. 3. Meteorological anomaly (solid line) of the sea level and barometric effects (dotted line) of Typhoon 8506.

OMA, OWA, URA, SIO, MIN, MUR, TOS, ABU である。

台風8719については，土佐清水，高知，室戸岬，潮岬，白浜，和歌山，徳島，高松，洲本，神戸，舞鶴，浜田の検潮記録を対象とした。これらの検潮所の位置を記号化し，Fig.2に示した。すなわち，それぞれ TOS, KTI, MUR, SIO, SIR, WAK, TKU, TAK, SUM, KBE, MAI, HAM である。

（1）台風8506の例

各検潮記録から予想潮（主として天文潮）を差引いて潮位偏差を求める。台風8506の場合，1985年6月30日－7月1日を対象として，潮位偏差を Fig.3の実線のように示した。また，気圧低下の効果を静水圧近似によって推定した結果を，Fig.3の破線によって示した。一般に，外洋では，台風高潮の潮位偏差は気圧低下の効果

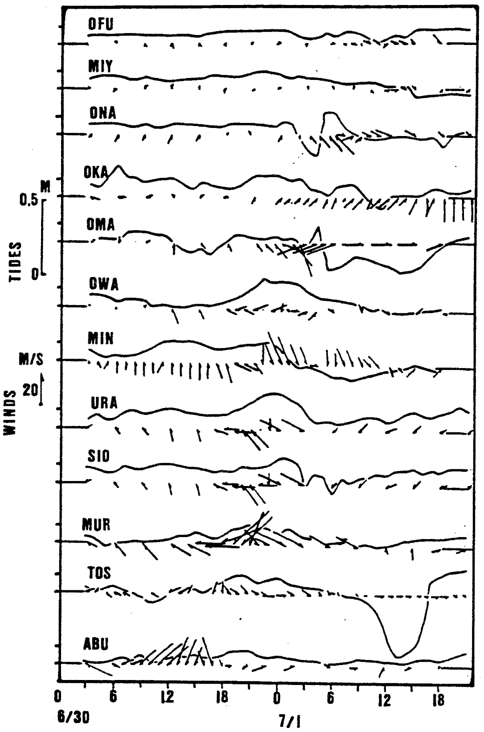

Fig. 4. Meteorological anomaly of the sea level for Typoon 8506. Solid line: non-barometric effects. Arrows: local winds.

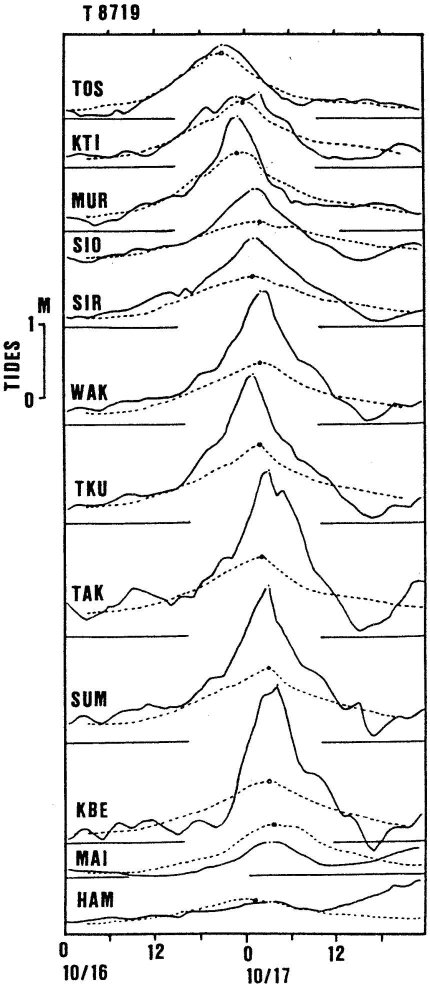

Fig. 5. Meteorological anomaly (solid line) of the sea level and barometric effects (dotted line) of Typhoon 8719.

として考えてよいとされているし，その理論的根拠も与えられている（たとえばNAKAMURA, 1981）。ただ，Fig. 3では，実線と破線とはかならずしも一致してはいない。

台風高潮の潮位偏差が非線型現象の場合には検討が複雑になる。簡単のため，線型的なデータ処理が可能なものと考えよう。このとき，Fig. 3に示した潮位偏差から気圧低下の効果を差引いた偏差は，Fig. 4の実線のようになる。Fig. 4には，各検潮所に対応した地点の風速を矢印によって示した。これによって，たとえば南部では，風向の変化が偏差の変化によく対応していることがわかる。これは，いわゆる風による吹き寄せ効果である。小名浜でも短時間ながらこの風の効果が認められる。

御前崎では，風が変わって，西風となると偏差が大となり潮位低下の原因となっている。油津，室戸岬，潮岬，岡田では，この偏差は比較的小さく，気圧低下の効果がとくに顕著なことがわかる。これは外洋性高潮の特徴とみてよいであろう。また，尾鷲と浦神とでは，台風が最も接近した位置にある時に偏差も最大である。これには，気圧低下の効果の増幅や検潮所周辺の地形条件も考慮すべきであろう。土佐清水では台風通過後に偏差の負値が異常に大きくなっている。

ここでは定性的検討にとどめたが，Fig. 3およびFig. 4では，偏差のさらに短時間の変動はわからない。

（2）台風8719の例

上述の台風8506の例と同様にして，1987年10月16－17日の台風8719の例を示す。潮位偏差はFig. 5に実線で示した。また，気圧低下の効果はFig. 5の破線のように推定される。Fig. 5の実線と破線のパターンは，Fig. 3にみられたパターンと対照的である。これは台風の経路の相異によるものである。

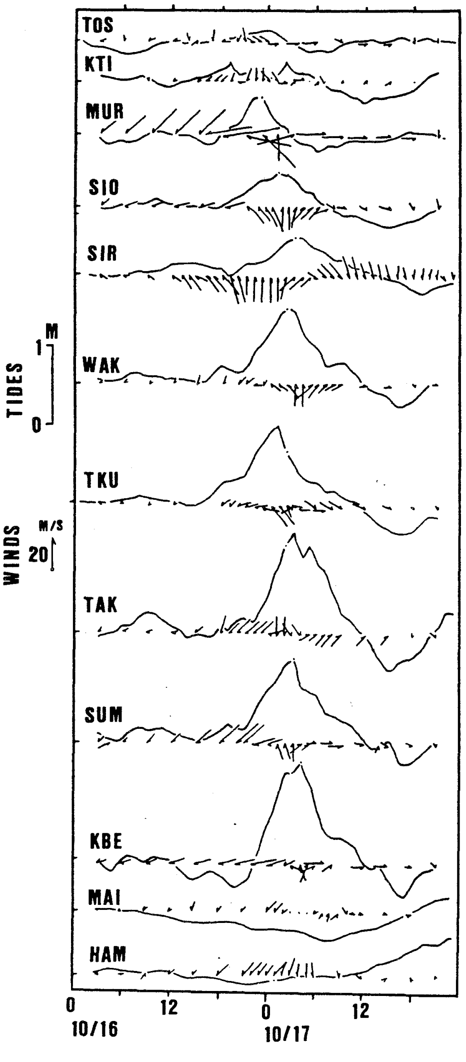

Fig. 6. Meterological anomaly of the sea level for Typhoon 8719. Solid Line: non-baromertic effects. Arrows: local winds.

潮位偏差から気圧低下の効果を除いた偏差を Fig. 6 に実線で示した。風は矢印によって示した。高知と土佐清水とでは気圧低下の効果を除いた偏差は小さい。舞鶴と浜田とでは台風通過後に偏差が顕著に大きくなっていることがわかる。これは日本海沿岸の高潮として検討すべきかもしれない。太平洋側の室戸岬，潮岬，白浜では偏差は最大約 0.5m である。これには増幅作用が関連しているようにみえる。さらに，紀伊水道・大阪湾の海域では，和歌山，高松，洲本，神戸の各検潮所で，風による吹き寄せ効果が非常に顕著である。とくに，大阪湾奥に位置する神戸では，偏差の最大は約 1.5m に達している。周辺の海底地形・海岸形状も考慮すべき因子であろう。

4．外洋に面した沿岸での高潮

高潮が岸沿いに移動する場合，これは，外力によって生じた Kelvin 波の問題として処理される（たとえば GILL, 1982，とくに p.398－403)。この場合，Rossby の変形半径と岸沿いの高潮のスケールとの大小関係が重要になる。Rossby の変形半径の決定には対象とする水深が与えられなくてはならないが，水深の値に任意性があると問題は力学的意義を失ってしまうことになる。しかし，時間のスケールが f^{-1} より小さいときは，このようなことは問題の対象ではなくなる。ここで，着目する緯度を $\zeta=30°\mathrm{N}$ とすると，

$$f^{-1} = \frac{1}{2\Omega\sin\zeta} \sim \Omega^{-1} \fallingdotseq 2.4\ \text{hours}。$$

ただし，Ω は地球自転角速度である。

台風 8506 および台風 8719 の例では，高潮偏差の時間スケールは約 20 時間であり，上の f^{-1} の値の約 10 倍とみてよい。台風の経路からみて，台風 8506 の場合には高潮偏差が Kelvin 型に近い挙動をするようであったとしても，台風 8719 の場合はそれほど現象は簡単ではない。

GILL (1982) は，1953 年 1 月 30 日－2 月 2 日の北海における高潮の例（ROSSITER, 1954）を引用している。FANDRY *et al.* (1984) は，岸に平行な風や気圧勾配は Kelvin 波の特性をもった変動をひきおこす要因であるとして KAJIURA (1962) や THOMSON (1970) の例を示している。

ところで，日本列島周辺で高潮災害をともなった台風の経路は，1934 年の室戸台風や，1954 年の伊勢湾台風，その他の多くの場合，台風 8719 の経路に近い。台風 8506 のような経路の場合には Kelvin 型の高潮があらわれるにちがいないが，かならずしもこれが高潮災害につながらない。高潮の力学的機構や予測についてなお今後の検討をまつ必要がある。

謝　辞

本研究をすすめるにあたって，気象庁の御好意により気象資料・検潮記録などの利用ができた。

文　献

DEACON, G.E.R. and M.B. DEACON (1982): Modern Concepts of Oceanography. Hutchinson Ross Publ. Co., Stroudsburg, Pennsylvania. 385pp.

FANDRY, C. B., L.M. LESLIE and R.K. STEEDMAN (1984): Kelvin-type coastal surges generated by tropical cyclones. J. Phys. Oceanography, **14**, 582-593.

GILL, A.E. (1982): Atmosphere-Ocean Dynamics. Int. Geophys. Ser., Vol. 30. Academic Press, N.Y. 662pp.

HANSEN, W. (1956): Theorie zur Errechnung des Wasserstandes und der Stroemungen in Randmeeren nebst Anwendungen. Tellus, **8**, 287-300.

KAJIURA, K. (1962): A note on the generation of boundary waves of Kelvin-type. J. Oceanogr. Soc. Japan, **18**, 49-58.

気象庁 (1961): 伊勢湾高潮の総合調査報告. 気象庁技術報告 No.4. 286pp.

NAKAMURA, S. (1981): On factors magnifying a storm surge. Proc. XIX Congress IAHR, New Delhi, Subject B(a), Paper No.5, 47-54.

NAKAMURA, S. (1988): An observation of factors related to typhoon. Proc. VI Congress IAHR-APD, Kyoto, Vol.4, 273-280.

中村重久(1988)：近畿圏沿岸の高潮災害の要因としての黒潮について. 京都大学防災研究所年報, No.31 B-2, 753-773.

NOMITSU, T. (1934): Coast effect upon the ocean current and the sea level. II. Changing state. Mem. Coll. Sci., Univ. Kyoto, Ser. A, **17**, 249-280.

ROSSITER, J.R. (1954): The North Sea surge of 31 January and 1 February 1953. Phil. Trans. R. Soc. London, Ser. A, **246**, 371-400.

THOMSON, R.E. (1970): On the generation of Kelvin-type waves by atmospheric disturbances. J. Fluid Mech., **42**, 657-670.

La mer 28: 63, 1990
Société franco-japonaise d'océanographie, Tokyo

学　会　記　事

1.　1989年12月1日　東京水産大学において平成2年度学会賞受賞候補者推薦委員会（第1回）が開かれ，委員長に鎌谷明善氏を選出し，推薦の方法及び次回の日程を決めた。

2.　1989年12月25日　東京水産大学において学会賞受賞候補者推薦委員会（第2回）が開かれ，評議員から推薦のあった候補者6名について審議し，2名が適格者として残された。この2名の代表的な論文リスト等を委員全員に送付し検討してもらうこととし，第3回委員会の日程を決めた。

3.　1990年1月12日　東京水産大学において学会賞受賞候補者推薦委員会（第3回）が開かれ，研究業績について審議の結果，落合正宏氏（都立大・理）が最適格者との結論に達し，この結論を会長に報告することとした。

4.　1990年2月14日　東京水産大学において平成2・3年度評議員選挙の開票が行われた。

5.　新入会員

（正会員）

氏　名	所　属	紹介者
小池　孝知	東京水産大学海洋生産学科漁業工学講座	高橋　正
エリック・シャルルリー	東京都港区南青山2-24-15 日本スリオ電子㈱	

6.　退会

近藤恵一，斉藤行正

7.　受贈図書

日本学術会議月報 31(2)
なつしま (104)
海洋産業研究資料 20(10)
海産研ニュース (16)
航海 (102)
日本鯨類研究所年報 昭63
1987/88年南氷洋鯨類資源予備調査の成果
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総産卵量による浮魚類の資源量推定法
　—北米カタクチイワシへの適用—
NTT R & D 38(11, 12), 39(1)
Preliminary Report of the Hakuho Maru Cruise KH-88-4
Bull. Ocean Res. Inst., Univ. of Tokyo (27)
科学通報 34(16～24)
水産学報 13(3)
韓国海洋学会誌 24(3)
青島海洋大学学報 18(2), 19(3, 4)
海洋与湖沼 20(3, 4)
Aquatic Living Resources 2(4)
Israel Oceanogr. & Limnol. Res. 12
Definicaoe classificacao dos stpos de navios de pesca (13)

日仏海洋学会役員・評議員

(1988～1989年度)

顧　　問　ユベール・ブロシェ　ジャン・デルサルト　ジャック・ロベール　アレクシス・ドランデール　ベルナール・フランク　ミシェル・ルサージュ　ロベール・ゲルムール　ジャック・マゴー　レオン・ヴァンデルメルシュ　オーギュスタン・ベルク

名誉会長　ユベール・セカルディ

会　　長　宇野　寛

副 会 長　髙木和徳

幹　　事　（庶務）須藤英雄，有元貴文；（会計）松生　洽，高橋　正；（渉外）有賀祐勝，佐伯和昭；（研究）関　文威，小池勲夫；（編集）山口征矢，渡辺精一

監　　事　久保田　穣，辻田時美

評 議 員　青山恒雄，阿部友三郎，有賀祐勝，石井丈夫　石野　誠，磯　舜也，井上　実，岩井　保，岩宮　浩，宇野　寛，大塚一志，岡市友利，岡部史郎，小倉通男，梶浦欣二郎，鎌谷明善　川合英夫，国司秀明，黒木敏郎，西条八束，佐伯和昭，坂本市太郎，坂本　亘，佐藤孫七　杉森康宏，須藤英雄，関　文威，平　啓介，髙木和徳，隆島史夫，高橋　正，高橋正征，多紀保彦，谷口　旭，辻田時美，寺本俊彦，鳥羽良明，冨永政英，中村重久，永田　豊，奈須敬二，奈須紀幸，根本敬久，野村　正，畑　幸彦，平野敏行，松生　洽，松山優治，丸茂隆三，三浦昭雄，宮本　悟，村野正昭，森田良美，柳　哲雄

（54名，会長推薦評議員を含む）

編集委員長　有賀祐勝

日本学術会議だより　№16

公開講演会盛会裡に終了

平成2年2月　日本学術会議広報委員会

日本学術会議は，平成元年度に主催の公開講演会を3回開催しました。今回の日本学術会議だよりでは，その公開講演会の概要に加えて，本会議が実施している国際的活動などについて，お知らせいたします。

日本学術会議主催公開講演会

本会議では，科学の向上発達を図り，行政，産業及び国民生活に科学を反映浸透させるという本会議の設置目的に沿うための活動の一環として，毎年，公開講演会を開催している。この講演会は，本会議会員が講師となり，学術的香気が高く，かつ，時宜にかなったテーマを選定して開催している。

今年度も3回の公開講演会を開催したので，その概要を以下に紹介する。

Ⅰ．公開講演会「人間は地球とともに生きられるか」

標記講演会は，去る平成元年10月27日（金）13時30分～17時に，本会議講堂で約280人の参加を得て開催された。

最初に，吉野正敏・第4部会員（筑波大学地球科学系教授）が，「地球の温暖化とその影響」と題して，大気中の二酸化炭素とフロン・メタンなどの増加による気温の上昇に伴う，農林水産業をはじめ人間の社会経済にもたらす大きな影響などについて述べた。

続いて，久馬一剛・第6部会員（京都大学農学部教授）が，「地球環境と農業のかかわり」と題して，人口の増加，消費水準の向上などが世界中で農業そのものの変貌を余儀なくしており，その中で土壌侵食や塩類化などによる生産力の退化（砂漠化）や，水質汚濁・土壌汚染などを引き起こしていることを指摘し，農業のあるべき姿について述べた。

最後に，藤井隆・第3部会員（名古屋大学経済学部教授）が，「地球環境の経営と人間社会の発展」と題して，地球環境の経営は，地球環境の科学的研究に加えて，人間社会の運行との相関についての研究が必要であることを指摘し，人間社会の持続的発展を考えていくための視点について述べた。

Ⅱ．公開講演会「〝人権の歩み〟から何を学ぶか―フランス人権宣言200年を記念して―」

標記講演会は，去る平成元年11月18日（土）13時30分～17時に，本会議講堂で約250人の参加を得て開催された。

最初に，弓削達・第1部会員（フェリス女学院大学長）が，「〝人権〟以前の世界」と題して，人権思想のなかったギリシャ・ローマ時代における人権思想の萌芽とも言うべきものについて，同時代の一哲学者の奴隷等をめぐる精神的苦闘を例にとって述べた。↗

次いで，大石嘉一郎・第3部会員（明治学院大学経済学部教授）が，「近代日本の人権思想―自由民権運動の人権論を中心に―」と題して，主として，明治時代の自由民権運動における人権論について，その特徴，特徴の起因となった当時の社会的条件，それが与えた影響などについて述べた。

続いて，杉本大一郎・第4部会員（東京大学教養学部教授）が，「科学技術と人権」と題して，近年の著しい科学技術の発展によってもたらされた，広い意味での「人権と自由」の様々な様相について，それらの事情と問題点などについて述べた。

最後に，南博方・第2部会員（一橋大学法学部教授）が，「人権の進化と創造」と題して，現在までの人権の進化の跡を回顧するとともに，最近における人権立法や人権思想を紹介しながら，今日生成しつつある現代型の新しい人権について述べた。

Ⅲ．公開講演会「くらしと学問の近未来―これからのくらしと学問―」

標記講演会は，去る平成元年12月8日（金）13時～17時に，仙台市の勾当台会館で約70人の参加を得て開催された。

この講演会の開催に当たっては，東北大学，宮城県教育委員会，仙台市教育委員会，河北新報社の後援を受けた。

最初に，藤咲暹・第7部会員（東北大学名誉教授）が，「長寿社会の条件―長生きを支える医学と医療」と題して，健康を阻害する危険や長生きできるための条件を充足するには厳しい現実があることを指摘し，長生きを支える医学と医療にとっての問題点を指摘し，それらの解決策について述べた。

続いて，澤登俊雄・第2部会員（国学院大学法学部教授）が，「犯罪現象への多様な接近」と題して，犯罪抑止や犯罪者の社会復帰などのための施策の推進には犯罪や犯罪者をつくりあげていくプロセスの分析など多様な視点からの検討が不可欠であることなどについて述べた。

最後に，上飯坂實・第6部会員（東京農業大学農学部教授）が，「森とむらと都市の共生」と題して，健全な森林づくりのために都市の住民と山村の住民が連帯することは，新しい人間尺度の文化の創造につながることを，日本と外国との場合を対比させて述べた。

（なお，これらの講演会の講演要旨は，「日学双書」として，（財）日本学術協力財団から出版されます。）

地球環境問題における工学研究の在り方について―第５部報告

このたび，本会議の第５部は，標記報告をとりまとめ，本会議運営審議会の承認を得て公表した。

（要　旨）

近年における人間活動の大規模化は，地球環境に急速な変化をもたらし，その変化が人類の生存基盤そのものさえも脅かすようになってきた。そのため，次の世紀に向けて人類が総力を上げて取り組むべき，極めて重要かつ緊急の課題として地球環境問題が広く国際的な関心を集めているのは周知のとおりである。

元来，この問題は，時間的にも空間的にも極めてスケールが大きく，かつ，気圏，水圏，地圏及び生物圏全体にわたる相互干渉の結果として現れるものだけに，対応策を選択するに当たって，従来とは異なった長期的，学術的かつ国際的視野に立ち，持続的に取り組む必要がある。また，局所的な現象に目を奪われた一時的な対応や規制ではなく，地球全体における持続的な発展という観点から，地球を一つのシステムとして捉え，自然環境と人間活動とをいかなる価値観に基づいて調和させていくべきかという視点から，総合的に取り組むべき問題である。

地球環境問題が人間活動の結果として現出したことを考えると，今なすべきことは，地球環境に配慮した健全な人間活動のために新しい工学的基準を導入するなどにより，人間活動と地球環境の調和に役立つ広く新しい学問領域を創出することである。

それは，地球環境と人間活動とを総合して一つのシステムとして捉え，そこにおける物質・エネルギー循環・エネルギー収支のあるべき姿を定量的に評価できる手法を開発し，人類が生存し得る新しい技術体系を構築する学問領域である。このような地球システムの工学を「地球システム工学」と呼ぶことにする。

このような新たな学問領域創出と新たな技術体系確立のためには，既往の学問分野からの協力により速やかに研究体制を構築する必要がある。このためには，当面，研究プロジェクトを設定することにより強力な研究推進を行う必要がある。我が国がかかる学問領域を率先して創造し，国内外の研究者とともに地球環境問題解決に取り組むことは，研究開発力，技術力に対する海外の期待というものを考えた時，我が国の責務と考えられる。

平成２年（1990年）度共同主催国際会議

本会議は，昭和28年以降おおむね４件の学術関係国際会議を関係学術研究団体と共同主催してきたが，平成２年（1990年）度には，２件増えて，次の６国際会議を開催する。

■国際土壌科学会議
　開催期間　平成２年８月12日～18日
　開催場所　国立京都国際会館（京都市）
　参加者数　国外1,000人，国内500人，計1,500人
　共催団体　（社）日本土壌肥料学会

■第22回国際応用心理学会議
　開催期間　平成２年７月22日～27日
　開催場所　国立京都国際会館（京都市）
　参加者数　国外450人，国内550人，計1,000人
　共催団体　日本心理学会 ↗

■第15回国際微生物学会議
　開催期間　平成２年９月13日～22日
　開催場所　大阪城ホール外（大阪市）
　参加者数　国外2,000人，国内3,500人，計5,500人
　共催団体　日本微生物学協会

■第11回国際数学連合総会及び第21回国際数学者会議
　開催期間　平成２年８月18日～29日
　開催場所　神戸国際会議場（神戸市）外
　参加者数　国外1,500人，国内2,000人，計3,500人
　共催団体　（社）日本数学会外６学会

■第11回国際神経病理学会議
　開催期間　平成２年９月２日～８日
　開催場所　国立京都国際会館（京都市）
　参加者数　国外600人，国内900人，計1,500人
　共催団体　日本神経病理学会

■第５回国際生態学会議
　開催期間　平成２年８月23日～30日
　開催場所　横浜プリンスホテル（横浜市）
　参加者数　国外900人，国内1,000人，計1,900人
　共催団体　日本生態学会

二国間学術交流事業

日本学術会議では，二国間学術交流事業として，毎年２つの代表団を外国に派遣し，各訪問国の科学者等と学術上の諸問題について意見交換を行って，相互理解の促進を図る事業を行っている。

平成元年度には，①10月25日から11月４日まで，イタリア及びスイスへ，渡邊格副会長以下５名の会員から成る代表団を，②12月４日から12日まで，インドへ，大石泰彦副会長以下６名の会員から成る代表団をそれぞれ派遣した。

イタリア及びスイス派遣代表団は，イタリアでは，イタリア学術研究会議，大学・科学技術研究省，ローマ大学，ローマ日本文化会館など，スイスでは，スイス学術会議，連邦内務省教育・科学局，スイス科学財団，ベルン大学，チューリッヒ大学などを訪問した。

各訪問先では，関係者との間で，それぞれの国の学術研究体制や科学技術政策などをめぐって意見交換が行われたが，特に，イタリアでは，研究行政の一本化を図るために，大学を文部省の管轄からはずして，大学・科学技術研究省を設置していることについて，また，スイスでは，連邦政府とともに，強い権限を持つ州政府が存在する同国の行政の仕組みと学術行政との関連について，それぞれ熱心に意見の交換がなされた。

インド派遣代表団は，インド国家科学アカデミー，科学産業研究会議，計画委員会，科学技術庁，ネルー大学，デリー大学，タタ基礎研究所などを訪問した。

各訪問先では，関係者との間で，科学技術振興方策及び両国間の今後の積極的な学術交流などをめぐって意見交換が行われ，また，政変の直後ということもあって，選挙の話から，経済力の向上，中産階級の躍進などの政治，経済の問題などについて熱心に意見の交換がなされた。

御意見・お問い合わせ等がありましたら，下記までお寄せください。
〒106 東京都港区六本木７―22―34
日本学術会議広報委員会　電話03(403)6291

賛助会員

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株式会社 高岡屋	東京都台東区上野 6-7-22
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株式会社 東急フーズミート	東京都品川区東品川 4-10-21
株式会社 西日本流体技研	長崎県佐世保市棚方町 283
日本アクアラング株式会社	神奈川県厚木市温水 2229-4
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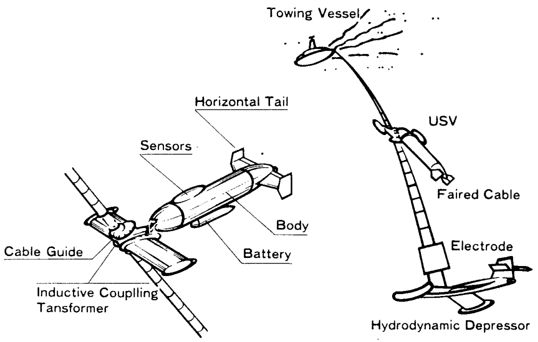
株式会社 読売広告社	東京都中央区銀座 1-8-14
渡辺機関工業 株式会社	愛知県渥美郡田原町神戸大坪 230
株式会社 渡部計器製作所	東京都文京区向丘 1-7-17

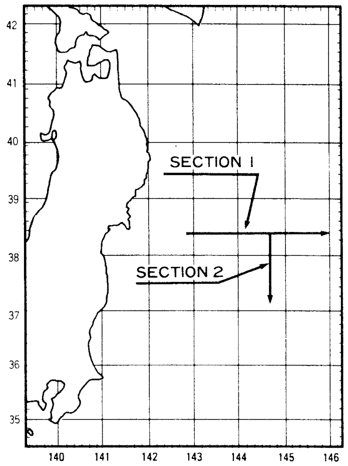
スライド式高速曳航体 JAMSTEC TSK方式

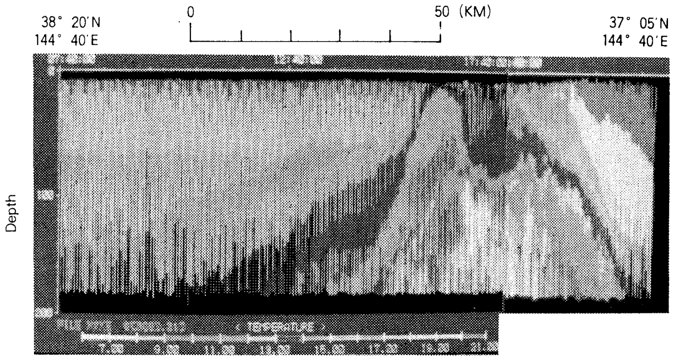
Underwater Sliding Vehicle System (USV)

○本システムは海洋科学技術センター殿の御指導によって開発されました。
○USVは小型かつ軽量で極めて優れた水中運動性能を有しております。
○電磁誘導伝送方式を使うことにより船上からのUSVの昇降運動制御及びリアルタイム信号モニターリングを行うことができます。
○取得データはFD及びハードディスクに記録し２次電算機処理に供します。



The USV system





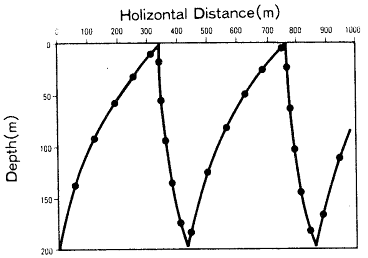
T.Sスライド式高速曳航体によって得られた三陸沖の水温鉛直分布のカラー画像。
(海洋科学技術センター殿から資料を御提供頂きました。)

SPECIFICATIONS

Towing Speed :0～8knots
Operation Dapth:Max.400m
Tow Cable :8mm hydrodynamically fared stainless steel wire rope with polyurethane coating

Sensor	Range	Accuracy
Conductivity	20～70ms	±0.05ms
Temperatune	−2～35℃	±0.05℃
Depth	0～400dbar	0.5%FS

Data Transport :Inductive Coupling Data Communication System
Sempling Rate :5times per second
Sensor Battery Life :50hours



Trajectory of the USV

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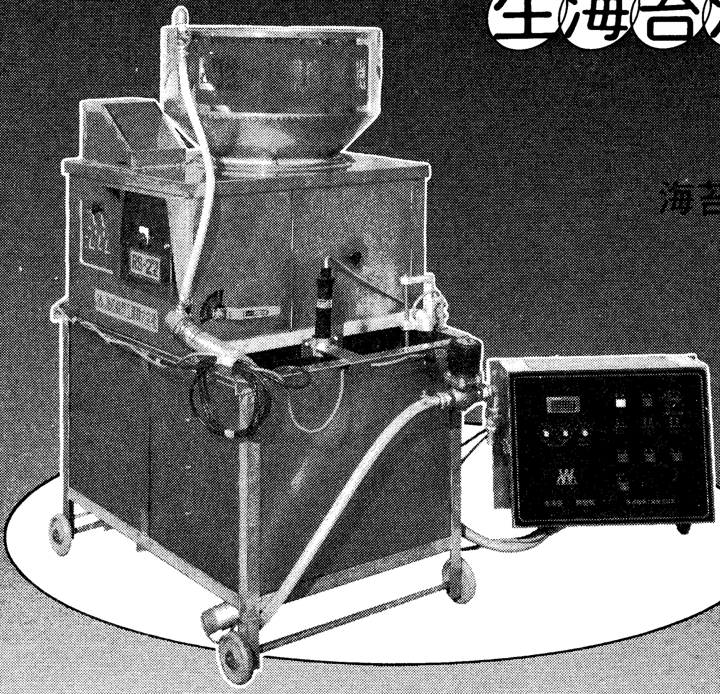

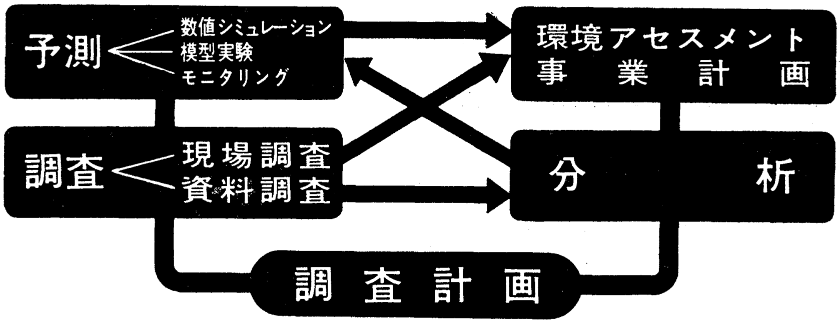
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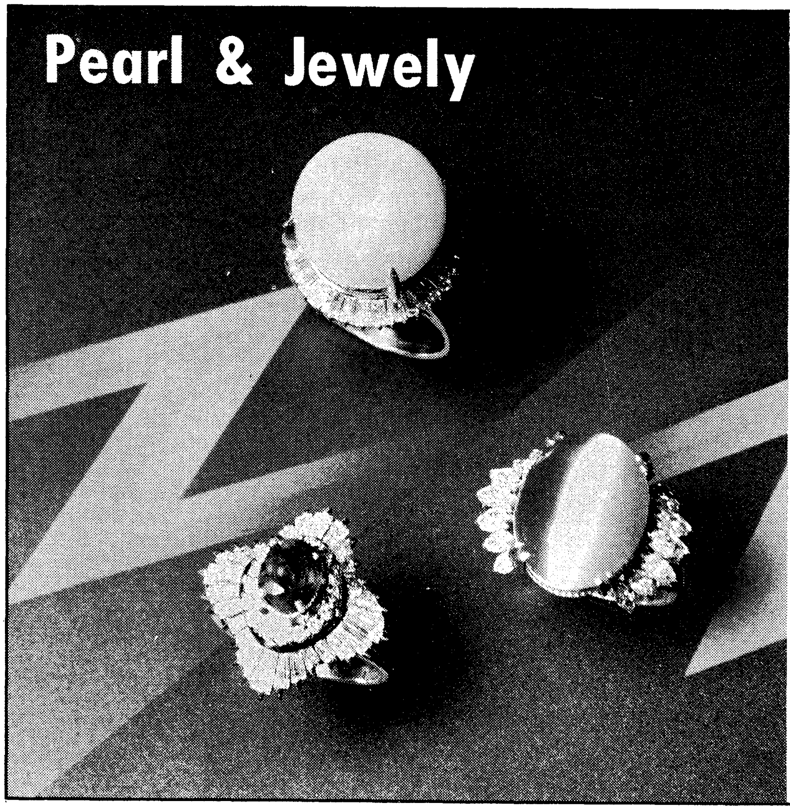
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