Decadal trend of the tidally-induced stratification in Fukuoka Bay: Its potential cause and influences

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Harmonic constants of astronomical tides are not always “constant” in coastal waters where the geography and bathymetry have been anthropologically altered. In fact, it was shown that the tide has gradually decreased in recent years around Japan (e.g., Tokyo Bay, Ise Bay, Osaka Bay, and Ariake Sea) mainly owing to the changes of the resonant period of the bay in constructing large amount of man-made structure (Unoki, 2003). It is therefore valuable to investigate secular trend of tides presumably occurred in Fukuoka Bay because massive construction projects have proceeded in the past decades. Of note, the ocean environment in small bays would be easily affected by the change of the tides and tidal mixing. For instance, it is reasonable to consider that weakened tidal mixing at neap tides intensifies the estuarine circulation in the summer coastal waters, and thus, the water temperature (salinity) decreases (increases) owing to the inflow of the cool and saline subsurface water from the neighboring open ocean (hereinafter, “estuarine-circulation phase”). Meanwhile, it is also reasonable to consider that the weakened tidal mixing at neap tides increases (decreases) the sea surface temperature (salinity) owing to the weakened vertical mixing (“mixing phase”).
In this study, we focused on the changes in the tidally-altered stratification of Fukuoka Bay (facing to the Tsushima Strait) using archived water temperature (T) and salinity (S) observed by the Fukuoka Fisheries and Marine Technology Research Center. The T/S data observed during the summer (June - August) from 1982 to 1998 were categorized into data obtained at spring and neap tides. It is interesting that, in the 1980s (1990s), the sea surface temperature at neap tides was lower (higher) than that at the spring tides. The suggestion is that weak (strong) tidal mixing remains (destroys) the summer stratification at neap (spring) tides in 1990s, whilst this tidal mixing process did not work well in 1980s. Also of particular interest is that the salinity in the bottom layer at neap tides was higher in 1980s than that in 1990s. This suggests that Fukuoka Bay belonged to the estuarine-circulation (mixing) phase in 1980s (1990s). In conference, we will provide the analytical results of how spring/neap tide influence the T/S in the bay. Moreover, we will present the potential cause(s) of why the above phase change occurred in the Fukuoka Bay. In addition, we now attempt to uncover its influence(s) on the surrounding atmospheric condition (e.g., sea-breeze) as well as oceanic one. The response revealed in the lower-level atmosphere over the Fukuoka Bay (and neighboring land) might occur as in the Seto Inland Sea, where the fortnightly tidal cycle actually alters the air temperature and wind magnitudes over the sea via changes in the tidal mixing (Iwasaki et al., 2015).

Keywords: tide, estuarine circulation, air-sea interaction, Fukuoka Bay, tidal mixing

Simulation of the Seto Inland Sea by using a nested-grid OGCM

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A nested-grid OGCM based on an ice-ocean coupled model, named COCO is used to investigate the flow field in the Seto Inland Sea. The model is composed of interactively coupled four models from a global model to the finest (about 500 m mesh) regional model covering the Seto Inland Sea. The model is integrated for one year during 2012 with potential temperature and salinity around Japan (outside the Seto Inland Sea) restored to reanalysis data. According to Zhang et al. (2016) who measured the net transport through the Seto Inland Sea by using reciprocal sound transmission, the net transport is westward (-1.3×10^4 m^3s^{-1}) on average in six months of 2012. The simulated net transport near the observational section during February-December 2012 is eastward (0.35×10^4 m^3s^{-1}) on average. Difference in direction of net transport between the observations and simulation may be partly due to assumption of northeast flow direction used in the observations. In the simulation, the time-averaged velocity field shows complicated structure. The net transport is estimated in a similar manner as in the observations: after calculating the velocity component along the observational section, the transport is estimated with the assumption of northeast flow direction. The resultant net transport is westward (-0.036×10^4 m^3s^{-1}) on average as in the observations though its magnitude is smaller.

Keywords: Seto Inland Sea, Ocean general circulation model, nesting

Circulation and haline structure of a microtidal bay in the Sea of Japan influenced by the winter monsoon and the Tsushima Warm Current

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Mooring and hydrographic surveys were conducted in Tango Bay, a microtidal region of freshwater influence (ROFI) in the Sea of Japan, in order to clarify the circulation pattern in the bay and its driving forces. Monthly mean velocity records at four stations revealed an inflow and outflow at the eastern and northern openings of the bay, respectively, which indicates an anticyclonic circulation across the bay mouth. The circulation was significantly intensified in winter, in accordance with the prevailing NW wind component of the winter monsoon. The anticyclonic circulation at the bay mouth was connected to an estuarine circulation that was evident near the mouth of the Yura River at the bay head. Surface salinity just offshore of the river mouth was closely related to the Yura River discharge, whereas in lower layers the offshore water had a stronger influence on salinity. Prior to a seasonal increase in the Yura River discharge, summer salinity decreased markedly through the water column in Tango Bay, possibly reflecting intrusion of the Changjiang Diluted Water transported by the Tsushima Warm Current. In contrast with the traditional assumption that estuarine circulation is controlled mainly by river discharge and tidal forcing, the circulation in Tango Bay is strongly influenced by seasonal wind and the Tsushima Warm Current. The narrow shelf may be responsible for the strong influence of the Tsushima Warm Current on circulation and water exchange processes in Tango Bay.

Keywords: water exchange, ROFI, microtidal bay, estuarine circulation, Tsushima Warm Current, Changjiang Diluted Water

Spatial difference of spring phytoplankton bloom dynamics in the Japan Sea

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Onset and magnitude of spring phytoplankton bloom impact higher trophic levels in the ocean. In previous, relationship between mixed layer depth and euphotic layer depth is considered as the key factor to onset of the bloom (critical depth hypothesis, CDH), but in recent, importance of turbulent mixing in surface layer is focused (critical turbulence hypothesis, CTH). In the Japan Sea (JS), onset of spring bloom is heterogeneous: chlorophyll *a* (Chl-*a*) concentration reaches maximum in April in the south, and it does in May in the north. This heterogeneity has been explained by the CDH in the previous studies, but the role of the turbulence mixing has not been considered. In this study, we aimed to explain this spatial difference in timing of bloom based on the mechanism of bloom, the CDH and the CTH.
For understanding the mechanisms, we calculated the weekly and monthly climatological values of mixed layer depth (MLD) from historical water temperature and euphotic layer depth (ELD), net heat flux (NHF), wind stress (WS), nitrate concentration, and satellite-derived sea surface chlorophyll *a* (Chl-*a*) concentrations. Additionally, ecosystem model based on NEMURO was constructed. This model added turbulence as the physical parameter: it is weak at the surface when NHF is positive. Onset of spring bloom was defined as when increase rate of Chl-*a* concentration was more than twice compared to the previous week.The JS was divided by temperature at 50 m depth and temporal variation of Chl-*a* concentration into four regions, the southern part (South), the subpolar front region (SFP), the northwestern region (NW), and the northeastern region (NE).
First, onset of spring bloom was not different among the areas. The Chl-*a* concentration began to increase at the timing when the NHF changed from negative to positive. This result supports CTH and lowering of the turbulence mixing is the controlling factor of onset of the spring phytoplankton bloom in the JS. Particular, in the SFP, the MLD is always shallower than the ELD during winter, but rapid increase of Chl-*a* concentration occurred: CDH is not supported in the SFP. The results from the ecosystem model support the CTH as well as the observations. When the turbulence mixing in surface layer was cancelled in the model, the beginning of spring bloom delayed, but when the turbulence was deal with as realistic, the onset of bloom was reproduced well in the model.
Second, the timing of peak of the bloom was not homogeneous as same as the previous study: it delayed in the NE. Since the onset of bloom was synchronous all over the JS, this results indicated that phytoplankton growth rate is different among the ocean. The growth of phytoplankton is controlled by temperature and nutrient concentrations as well as the light condition, but in the model, the difference of former two parameters did not affect the timing of peak. On the other hand, it was effected by the depth of mixed layer. In the NW, winter mixed layer was deeper than the other three regions, and our model indicated that phytoplankton vertically transported by this deep mixing to the layer with low light level in the NW. This phenomenon supports CDH.
In conclusion, we succeed to revise the dynamics of spring bloom in the JS based on the CTH as follows: the onset of phytoplankton bloom is controlled by the turbulence mixing, and its development is controlled by the degree of mixing as well as the turbulence.

Keywords: spring bloom, critical turbulence hypothesis, critical depth hypothesis

An estimate of the tsunami-debris quantity washed ashore on the US and Canadian beaches, based on a webcam monitoring and a particle tracking model experiment

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The 3.11 Earthquake occurred in 2011 triggered a great tsunami in the Tohoku area, Japan. The Ministry of Environment, Japan estimated that about 5 million tons of Japanese tsunami marine debris (JTMD) flowed out into the North Pacific, and that 1.5 million tons (30%) of JTMD is still floating in the North Pacific. Thus, they have a potential to reach the North American and Pacific Islands’ coasts even at present time. In particular, an attention is placed on coastal Japanese species carried by JTMD because these invasive species might damage the indigenous marine ecosystem. Particle tracking models (PTMs) might be capable of computing JTMD motion in the ocean circulation. However, it is difficult to determine by the PTMs alone if modeled particles in the ocean are washed ashore onto the land, because the stranding must be dependent on nearshore processes that might not be resolved in modeled ocean currents (hence, PTMs) sufficiently. Also, re-drifting processes of stranded particles into the ocean should be incorporated into the PTM; otherwise the estimate of debris quantity on beaches remains unreliable. The webcam monitoring on a beach in Newport, Oregon, provides us with a simple scenario of stranding/re-drifting processes: the debris on the beach increased during the downwelling-favoring winds, and rapidly decreased under the onshore-winds at spring tides by re-drifting. The PTM in the present study consists of two models: one is a PTM to reproduce the JTMD motion in the North Pacific using an ocean reanalysis product (ocean circulation) and satellite-derived winds (leeway drift), and the other is a “sub-model” to give the criterion whether or not the modeled particles are washed ashore on the neighboring land grid cell, and whether or not they return to the oceanic domain from the land. The satellite-derived winds on the grid cells neighboring the land boundary were used for the criterion in the sub-model. In the present study, we attempt to estimate the abundance of JTMD washed ashore on the western coasts of US and Canada during the period 2011 through 2016. We also attempt to find the beaches on which the massive amount of JTMD has been washed ashore to provide a “hazard map” of invasive species. As the results, in total, 30,000 tons of JTMD potentially exists on the US and Canadian beaches at the present time. Furthermore, the model results states that the invasive spices on the tsunami debris have not washed ashore widely on the entire US and Canadian beaches. They have been washed ashore on the relatively narrow area (<1000 km) around Vancouver Island, which might act as a “gate” of the invasive spices carried by the tsunami debris.

Keywords: Japanese tsunami marine debris, particle tracking model, western coast of the North America

Effects of high frequency internal waves on the formation of moon jellyfish aggregations

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Several jellyfish species such as moon jellyfish are known to frequently form dense patchy aggregations. These aggregations cause some damages on human activities, for example clogging seawater intake of power plant and breaking fishing net. Furthermore, their large abundance is concerned to have some harmful effects on coastal ecosystem. However, not only forming mechanisms of patchy aggregation, but also three dimensional distributions of the aggregations have not been revealed. In this study, we conducted observations for moon jellyfish using scientific echo sounder in order to obtain a three dimensional distribution of its aggregations. We then assumed that internal waves might affect in aggregation formation because the high frequency internal waves, whose period is about 10~20 minutes, occurred frequently around the observation area. In order to confirm this idea, we performed calculations of particle tracking in a flow field for idealized internal waves and examined the aggregation mechanisms from calculation results.

Observations using scientific echo sounder (Sonic KCE-300, frequency: 120 kHz and 38 kHz) were carried out during the summer of 2013~2016 in the Hokezu Bay of the Bungo Channel, Ehime, Japan. The observed aggregations can be divided broadly into following three patterns: (1) dense and patchy aggregation, namely, elongated or spherical shape, and some of them had hollow structure in its vertical cross sections such as reported by Churnside et al. (2015). In other words, the three dimensional form of the elongated aggregation was like a tube as long as several hundred meters; (2) layer structure distributing in a broad area at the same depth of pycnocline; (3) wave structure within the vertical cross section.

Assuming that the jellyfish individuals are completely passive to surrounding flow, particle tracking calculations in the flow field induced by high frequency internal waves of observed period and wavelength in the Hokezu bay were carried out. As a result, while wave structure analogous to the aggregation pattern of (3) was represented, dense patchy structure such as the pattern of (1) could not be reproduced. Therefore, it is difficult to consider that the patchy aggregation was formed only by a flow field. Active swimming behavior of jellyfish must be also involved in the formation of aggregation. In addition, since the results of particle tracking calculation can also be considered to represent the distribution of zooplankton, it is also suggested that the patchy aggregation cannot be formed as a result of foraging behavior of jellyfish. In the future, we will configure a jellyfish swimming model based on field observations and combine it with particle tracking model in the idealized flow field in order to reveal the formation mechanisms of jellyfish patchy aggregation.

Keywords: moon jellyfish, aggregation, internal wave

Hypoxic water mass in Jakarta Bay, Indonesia

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[Introduction]
Jakarta Bay is an open bay located at the northern coast of West Java (Fig. 1). Its width is about 30 km and length is about 16 km. It is located in the equatorial area at the latitude of 6° S. Its mean depth is 15 m and there are 13 rivers flowing into Jakarta Bay (Wouthuyzen et al., 2011). Active commercial fishing is conducted in Jakarta Bay. However, recently massive fish kill often happened. It is supposed that the upwelling of oxygen depleted water (hypoxic water mass) would induced the massive fish kill (Sachoemar and Wahjono, 2007). However, it was not confirmed because of the lack of dissolved oxygen data. Not only Jakarta Bay, there are few information of hypoxic water mass in the coastal sea in the tropical zone especially equatorial area. The hypoxic water mass happened in many semi-enclosed bays in summer and became a big environmental problem in the temperate zone; e.g. in Chesapeake Bay, Tokyo Bay and Ise Bay. In these temperate bays, the surface heating and the increase of river discharge from spring to summer enhance the stratification and trigger the generation of hypoxic water mass. But the climate in the tropical zone is largely different from the temperate zone (e.g. the seasonal temperature variation is very small). Therefore, if the hypoxic water mass was formed in Jakarta Bay, its formation mechanism would be different from the temperate zone. So, in order to clarify the seasonal variation in dissolved oxygen (DO) in Jakarta Bay, field surveys were conducted in this study.
[Methods]
We made water quality survey in Jakarta Bay 6 times between December 2015 and February 2017 about every 3 months. In each survey, the casts of multi-parameter water quality profiler were conducted at 26 to 29 stations in Jakarta Bay. The dates of the survey were shown in Table 1. The survey was carried out during 5 to 6 hours beside in December 2015 when it took 2 days to make the survey. At each station, the vertical profiles of temperature, salinity, DO, chlorophyll fluorescence and turbidity were measured with a RINKO Profiler (JFE Advantech Co.) and the transparency was measured with a Secchi disk. Only in the survey in December 2015, an AAQ1183 Profiler (JFE Advantech Co.) was used instead of the RINKO Profiler.
[Results and discussions]
Hypoxic water mass was observed in all the 6 surveys in Jakarta Bay (Fig.2), the minimum DO was less than 2 mg/L in all the surveys. It suggests that the hypoxic water mass was formed throughout the year in Jakarta Bay. Seasonally, the hypoxic water mass was diminished in February when it was in the mid-rainy season (North West Monsoon). On the other hand, the hypoxic water mass most developed in November to December when it was the transition from the dry season to the rainy season. The hypoxic water mass often formed in the area with the bottom depth of 5 to 15 m especially in the eastern part of the bay head. In May 2016, the DO was less than 3 mg/L even in the surface layer in the eastern coastal area. It indicates that the upwelling of the hypoxic water mass really happened. The thermal stratification was not formed or weak throughout the year, the temperature difference between surface and bottom layers was less than 2 °C. The haline stratification was observed throughout the year. The stratification weakened in February when the hypoxia was reduced. In November to December, the stratification was relatively strong.
Since Jakarta bay is located in the equatorial area, surface heating tends to overwhelm the surface cooling. Therefore, the vertical convection reaching at the bottom unlikely happens. However, during the

mid-rainy season, the vertical mixing would be enhanced caused by the strong wind and high wave due to the North West Monsoon. As it would reduce the stratification and increase the oxygen transport to the bottom layer, the hypoxia would be reduced. In the deep tropical lakes and reservoirs which are not located at high altitude, the permanent thermocline was formed (oligomictic) (Hutchinson and Loffler, 1956). The water tends to become hypoxic below the thermocline in these lakes and reservoirs (e.g. Lehmusluoto and Machbub, 1995). However, in the case of Jakarta Bay, though the depth was shallow and the stable thermocline was not formed, the hypoxic water mass was formed throughout the year. It would be due to the 3 reasons. 1) This bay tends to be stratified because of the weak tidal mixing (tidal range is less than 1 m) and enough river discharge. 2) As it is difficult to occur the continuous vertical convection due to the surface cooling, the water column tends to keep stratification. 3) The oxygen consumption rate in this water may be high.

Keywords: hypoxic water mass, Jakarta Bay, Indonesia, tropical zone, dissolved oxygen

Table 1 Observation dates
8,9 Dec. 2015
9 Feb. 2016
29 May 2016
20 Sep. 2016
27 Nov. 2016
10 Feb. 2017

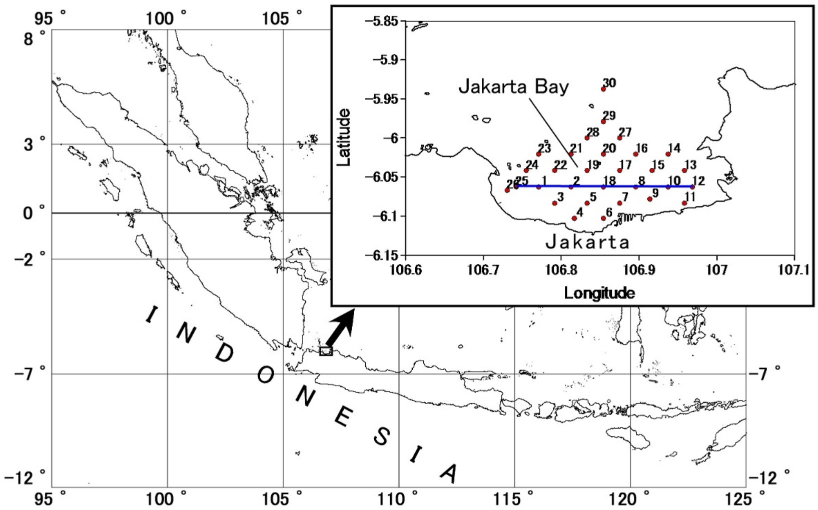

Fig.1 Map of Jakarta Bay and location of the observation stations

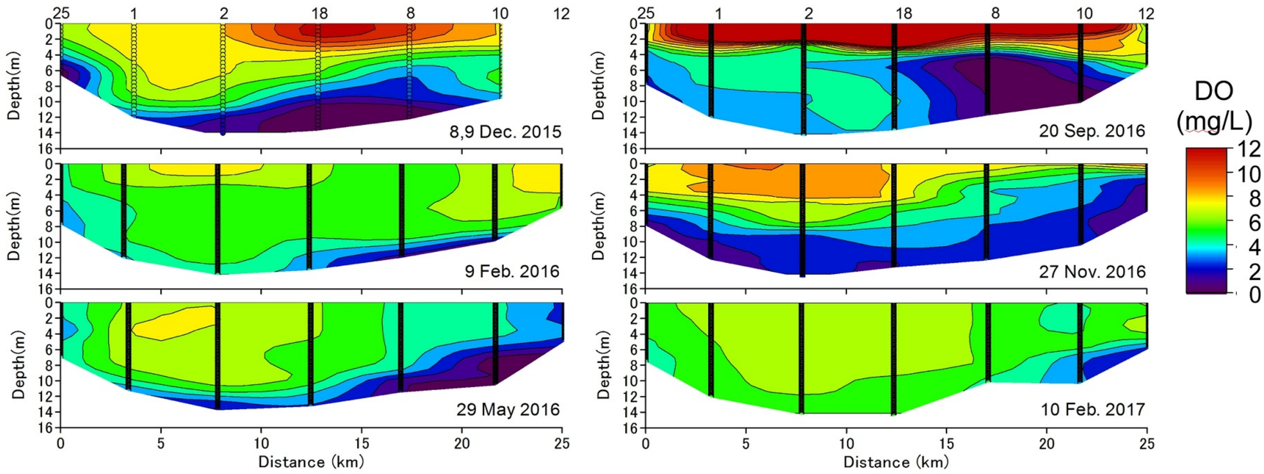

Fig.2 Distribution of Dissolved Oxygen along the longitudinal line in Jakarta Bay

Seasonal variation in hypoxia and its behavior in the Upper Gulf of Thailand

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Upper Gulf of Thailand (UGoT) faced to Bangkok of capital city of Thailand is one of the important coastal areas because of high fishery production. Recently, enormous organic matters and nutrients are supplied from land area through 4 large rivers. As the result, eutrophication, red tide, and hypoxia occur and marine environment in the UGoT becomes worse. In fact, cultured mass mortality of shellfishes happens every year at aquaculture farm in the eastern part of UGoT. Regardless of the circumstance, dissolved oxygen (DO) distribution and its seasonal variation are unclear due to limitation of observed data there. In the present study, we have conducted 7 times field survey from 2014 August to 2015 June at stations covered whole UGoT. It is found from our observation that hypoxia occurs from June to November and DO concentration in the bottom layer is less than 1 mg/l. As for distribution of hypoxia, hypoxia happens in the central part of bay head in June and then expands to northeastern part of the bay head. The hypoxia occurs in the half of UGoT in September and distributes in the northwestern part of the bay head. It is noteworthy that location of hypoxia changes from eastern side to western side of bay head through June to November. Since UGoT locates in tropical region, density stratification is formed by fresh water supply from rivers. Therefore, it is expected that distribution of hypoxia relates to that of surface salinity. However, we cannot see such relation. On the other hand, oxygen consumption rate in the water correlates surface chlorophyll-a concentration. Although we have compared DO concentration in the bottom layer with intensity of stratification, oxygen consumption rate, surface chlorophyll-a, and so on, we could not explain the movement of hypoxia area from east to west.
When location of hypoxia changes from east to west, monsoon direction also changes from southwest to northeast monsoon. It is expected that circulation in the UGoT is varied by variation in wind field and low DO water mass transports to the other area. We develop a 3-dimensional numerical model to reproduce current fields during our observation period. In the model, we consider tidal, density-driven, and wind-driven currents applying tidal variation at open boundary, river discharge from 4 large rivers, and wind and net heat flux at sea surface. The model well reproduces tide and distribution of water temperature and salinity. From the results of the model, it is found that bottom circulation changes when hypoxia area in eastern part of the bay head moves to west. We are developing lower trophic ecosystem model with 5 compartments, nutrient, phytoplankton, zooplankton, detritus, and DO. At the presentation, we will explain generation mechanism and cause of movement of hypoxia from the results of the coupled physical-ecosystem model.

Keywords: Hypoxia, Tropical region

Observation of Generation and Disappearance of Hypoxia in the Western Part of Nanao Bay

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In order to investigate the generation and disappearance of hypoxia in the western part of Nanao Bay located on Noto Peninsula, changes in water temperature, salinity, dissolved oxigen (DO) and current in Nanao Bay were observed from June to October, 2016.The generation and disappearance of hypoxia (DO less than 2mg/L) in the bottom layer (8.5 m depth) was repeated at several days interval. Hypoxia gradually appeared during several days and disappeared in hours. Hypoxia was observed from late June to early October and was the most frequent in August coinciding with high water temperature. In the case of hypoxia observed on June 24, DO did not changed significantly in the surface layer (1 m depth) but gradually decreased in the bottom layer from ca. 8 mg/L to ca. 2 mg/L during 3 days. Since salinity stratification was only found around estuary after precipitation on June 23, the salinity cannot be a main factor for hypoxia. Current velocity in the bottom layer was low from June 22 to 24. Therefore, stagnant flow and high water temperature were presumed to be the cause of hypoxia. On June 25 when strong southwestern wind blew in Nanao Bay, eastward flow occurred in the surface layer, whereas a strong westward flow exceeding 20 cm/s occurred in the bottom layer. DO in the bottom layer significantly recovered to ca. 8 mg/L with increasing current velocity. Water temperature in all layers decreased when the current in the bottom layer was strong. These results suggest that the wind-driven current in the surface layer to the leeward side had brought flow in the bottom layer toward the windward side as the compensation flow. As a result, vertical mixing was promoted and oxygen was supplied to the bottom layer.

Keywords: Nanao Bay, Hypoxia, meteorological factor

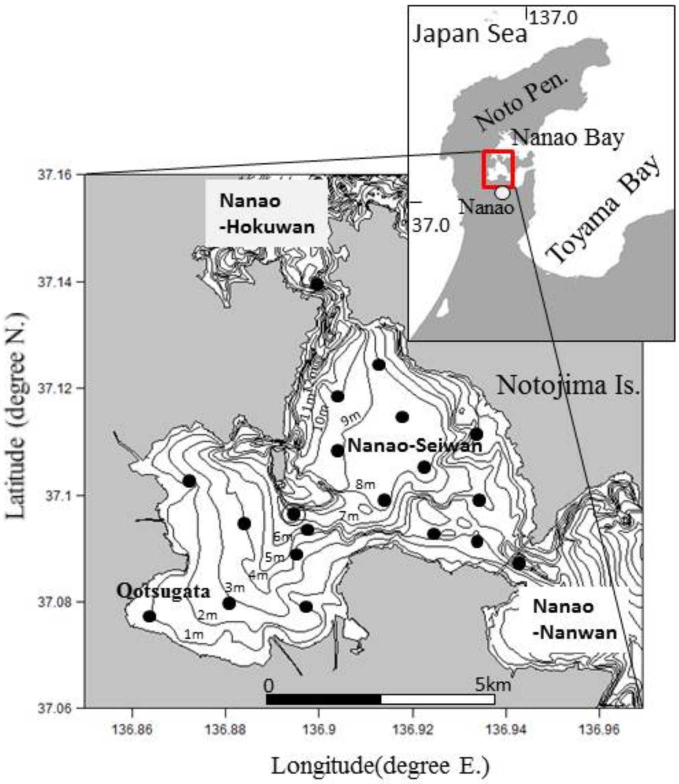

Fig.1. Location of observation stations in Nanao Bay (● indicates the CTD observation stations)、◉ indicates the temperature, current, and DO continuous mooring observation station).

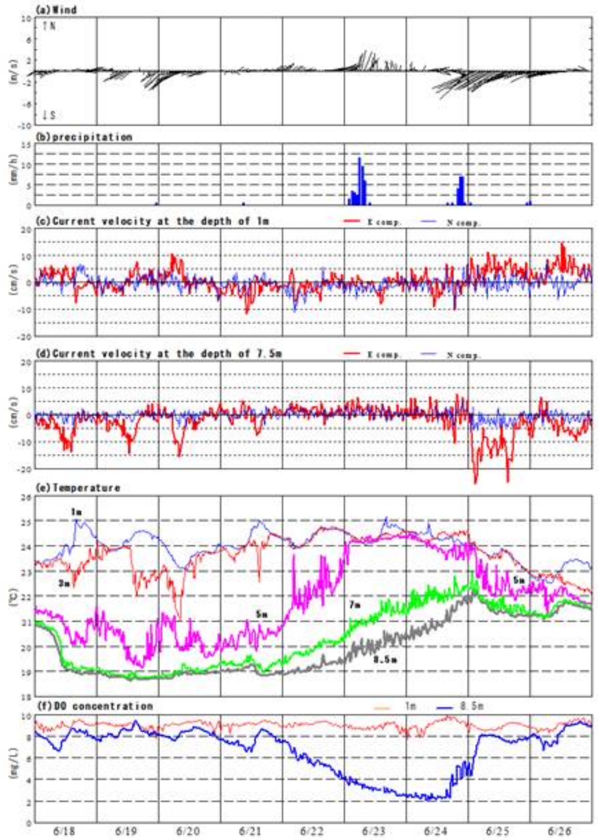

Fig.2. Temporal variations in (a)wind, (b)precipitation at Nanao, and (c)current velocity at the surface layer(1m), (d)current velocity at the bottom layer(7.5m), (e)Temperature at the depth of 1m, 3m, 5m, 7m, 8.5m, and (f)DO concentration at the surface and bottom layers from June 18 to 26 in 2016.

Monitoring for understanding marine condition in Wakasa Bay:Characteristics of seasonal variation in backscatter intensity measured by ADCP

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Wakasa bay is one of the bays facing the Japan Sea and its marine environment is strongly influenced by Tsushima Warm Current flowing near the shore. This area is known as a good fishing grounds for the set-net fishery and the trawl fishery. Recently, a monitoring system has been constructed to understand the fishing ground environment in Wakasa Bay. Water temperature, salinity and current are measured using moorings and real time buoys under this system, and the data collected by real time buoy are utilized for fishermen via web site. In this study, we focused on temporal variations of the backscatter intensity measured by an ADCP (Acoustic Doppler Current Profiler). To reveal the characteristics of variations, the ADCP data collected at a mooring point around the baymouth were analyzed. In addition, the characteristics of temporal variation of the backscatter intensity were compared with the temporal variation of physical and biological data such as water temperature, salinity, and fish catch. The data of water temperature and current collected by the monitoring system showed that the seasonal variation of the Tsushima Warm Current was closely related to the decrease of the backscatter intensity of the ADCP and the change of the fish catch in summer.

Keywords: monitoring system, Wakasa Bay , Tsushima Warm Curernt

Influence of Density Field on *Kyucho* and Bottom Intrusion in the Bungo Channel

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Occurrences of two density currents (*kyucho* and bottom intrusion) are known in the Bungo Channel, located between Kyushu and Shikoku, Japan (Takeoka et al., 2000). A *kyucho* is an intermittent intrusion of warmer water into the upper layer from the Kuroshio. A bottom intrusion is an intermittent intrusion of colder water into the lower layer from the bottom layer of continental slope. A *kyucho* in the channel is formed by the collision of a warm filament generated along Kuroshio front with the southwestern coast of Shikoku. The *kyucho* can flow into the central region of channel during a neap tide and warming period when vertical mixing is weak. A bottom intrusion is observed during a neap tide when the Kuroshio approaches the east coast of Kyushu (Kaneda et al., 2002a, b), however; its physical process is not fully understood. Strong bottom intrusions were observed five times during mid-November and mid-December 2013 in the southwestern coast of Shikoku (Fukuura Bay, Ehime) when temperature in the lower layer dramatically decreased (maximum: -4.0°C day^{-1}). In the present study, these bottom intrusions were analyzed using vertical temperature profiles along the coast of Shikoku measured by Ehime University and JF Ehime. Influence of density field inside the channel on *kyucho* and bottom intrusion was evaluated, using the observational data of Ehime Fisheries Research Center.

As the vertical temperature profiles were analyzed, we observed that both warmer and colder water alternately passed through the whole layer of Okinoshima Island, south of Bungo Channel. Strong bottom intrusions were seen when this colder water passed by Fukuura, the southernmost station in the channel. Temperature increases due to the *kyucho* were detected in the upper layer of Fukuura, after the warmer water passed through Okinoshima Island, however, the scale of increase was lower in Fukuura than in Okinoshima Island. As the bottom intrusions propagated into the central region, the strength dropped while the few *kyucho* propagated. The density field along the channel was analyzed to figure out a factor that only the bottom intrusions propagated into the central region. In the upper layer, the density was greater in the south than in the north in November 2013, and the water tended to move southward, thus the *kyucho* was interrupted. In the lower layer, the density was higher in the south than in the north, and the water tended to move northward, thus the bottom intrusions flowed into the central region. The previously observed data demonstrated that *kyucho* tended to be interrupted during October and November due to salinity increase in the upper layer of the south. Bottom intrusions tended to be interrupted between December and April of next year due to seasonal cooling in the north. Kaneda et al. (2002) only observed *kyucho* between December 1995 and April 1996 due to the density structure inside the Bungo Channel.

Keywords: Bottom intrusion, Kyucho, Bungo Channel, Kuroshio

Seasonal and interannual variations in the nutrient concentrations in the Bungo Channel, Japan

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The Bungo Channel is a channel connecting the Seto Inland Sea and the Pacific Ocean. The hydrographic condition in the Bungo Channel has been suggested to be strongly influenced by the intrusion of oceanic water from the Pacific Ocean. In this study, we focus on the spatial and temporal variations of the nutrients in the Bungo channel. We used field data of three nutrient elements (nitrate, phosphate and silicate), water temperature and salinity collected by the Ehime Research Institute of Agriculture, Forestry and Fisheries from 1991 to 2005 with an interval of one month. The nutrient concentrations were highest over the continental shelf slope in the southern area of the Bungo Channel during all seasons, and the interannual variations were also highest in the same area. In summer, water mass with relatively high concentration of nutrients was widely spread in the bottom layer of the channel. The nutrient concentrations in the middle and bottom layers in summer also showed large interannual variations. The large interannual variations of nutrient concentration from the shelf slope to the bottom layer of the channel are likely also associated with the bottom intrusion of oceanic water into the channel.

Keywords: Seto Inland Sea, field observations, nutrients, bottom intrusion

Marine Environmental Changes Caused by Destruction and Reconstruction of the Bay-mouth Breakwater

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Kamaishi Bay, a small bay on the Sanriku ria coast, is located in the northeastern part of Japan. Since the bay had been heavily damaged by a large tsunami associated with an earthquake off Chile in 1960, a bay-mouth breakwater was constructed in the bay by the Japanese government. The bay-mouth breakwater was very huge (about 2 km length) and the deepest in the world (63m depth). In 2011, surprisingly, it was destroyed by the giant tsunami following the Great East Japan Earthquake (hereafter referred to as Great Earthquake). The destroyed bay-mouth breakwater, however, is currently being reconstructed again. We have therefore investigated a sequence of marine environmental changes in the bay, using CTDO (temperature, salinity, depth and dissolved oxygen) data obtained by ship-board observations before the Great Earthquake, just after it, and at present (under the reconstruction of the breakwater). The results are summarized as follows.
Before the Great Earthquake (in 2009), the bay-mouth breakwater had a negative effect on the marine environment in the bay, although it provided a calm environment there. That is, oxygen deficiency occurred at the inner foot of the bay-mouth breakwater during the season of stratification, especially in the fall season, where a stagnant region formed. This is because water exchange between inside and outside the bay was prevented by the bay-mouth breakwater. Just after the Great Earthquake (in 2011), on the other hand, the oxygen deficiency is reduced, since the stagnant water tended to be removed by the water exchange between inside and outside the bay. At present (in and after 2015), however, the oxygen deficiency is reappearing, because the water exchange begins to be prevented again by the bay-mouth breakwater that is being reconstructed. In other words, the marine environment is getting worse again in the lower layer in Kamaishi bay.

Keywords: Water exchange, Bay-mouth breakwater, Kamaishi Bay, Great East Japan Earthquake

Nutrient Status of Otsuchi Bay and the major rivers flowing into it on the Sanriku Coast of Japan: 6 Years after the Great East Japan Earthquake

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The massive tsunami on 11 March 2011 severely damaged coastal fauna and the infrastructure of many coastal communities, including sewage treatment systems and fishery facilities. It also delivered massive amounts of debris and soil from landside into bays and heavily disturbed seaweed and seagrass beds. The disturbance has raised concerns about alterations in the nutrient status (the concentration and stoichiometry of major nutrients) of the affected bays. We will report time-series data on the nutrient status of Otsuchi Bay, an embayment located within the severely damaged region from March 2011 to March 2017. We compared data collected after the tsunami with those collected before the tsunami to evaluate possible tsunami-related impacts on nutrient status of the bay and the major rivers flowing into it. Anomalous features was noted in the first years after the tsunami: 1) remarkable accumulation of nitrite and silicic acid in summer of 2011; 2) remarkable accumulation of phosphate during the mixing period between November 2011 and January 2012 when the total inorganic nitrogen to phosphate (TIN/P) ratio was substantially reduced (ca. 6) relative to the typical ratio observed during the pre-tsunami period (ca. 10). This low TIN/P ratio was due to the high concentration of phosphate that was inferred to have originated from land-derived debris and sediment. In contrast, during the mixing period of the subsequent 2 years (2012–13 and 2013–14), the TIN/P ratio increased to reach a value of 12–13, which is greater than the typical value before the tsunami. Although the TIN/P ratio reduced slightly during the mixing period of the following 2 years (2014–15 and 2015–16), the average ratio was still higher than that before the tsunami. In this presentation we will report results obtained in the 6th year.

Keywords: the 2011 off the Pacific coast of Tohoku Earthquake, tsunami, Sanriku Coast, Nutrient status

A comparison between the 1D diffusion coefficient of beached litters in the cross-shore direction and surf zone diffusivity off Wadahama beach, Nii-jima Island, Japan

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Recently, marine litter is widely recognized as a global environmental problem. In addition to large marine debris, small plastic fragments are significant concern because they can be found anywhere in the ocean, coastal regions, and beaches. It is well known that marine debris gradually degrade into small plastic fragments on a beach because of exposure to ultraviolet radiation, heat of the sand, and mechanical erosion. Since long-term stranding on the beach enable marine debris to degrade into small plastic fragments, an understanding of the residence time of litters on a beach can widely applied to preventing the fragmentation of litters and mitigation of plastic pollution on the beach. In the previous studies by Kataoka et al. (2013), it is clarified that reduction of litter population on the beach can be approximated as an exponential function, because the backwash process obeys a diffusion process. The diffusion coefficient can be obtained by measuring their residence time on the beach. To estimate their residence time, Mark-recapture experiments (MREs) are often conducted. However, it is too hard to conduct these experiments on beaches in all part of the world because they consume enormous time and labor. Thus, the previous study proposed that the diffusion coefficient of marine debris is associated with that in the surf zone during storm events. These coefficients are connected with a constant determined by comparing two coefficients. In the present study, to estimate the constant, we conducted the MRE for diffusion coefficient of marine debris on Wadahama beach, Nii-jima Island and a Neutral Particle Experiment using video imaged of the surf zone. We will present these experiment results and relationship between two diffusion coefficients in detail.

Keywords: Beached marine debris, Diffusion coefficient, Mark-recapture experiment, Neutral particle experiment

Horizontal two-dimensional pattern formation of chlorophyll-a in ecosystem model with vertical mixing process

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In the Toyama Bay, chlorophyll-a in the surface layer of a few meters increases in the rainy season of Jun to July, while forming the counterclockwise pattern (cf. Fig.1). This characteristic distribution is considered to be found in the relationship between oceanic physical processes (advection and diffusion) and ecosystem in the Toyama Bay. However, the formation and development mechanism are not revealed in detail. Then, we investigate the mechanisms of pattern formation using a satellite image, ocean observation data, and physics-ecosystem modelling.
Especially, we focus on the vertical mixing process and the inflow of nutrient from the river.
In this study, we used the NPZ model as an ecosystem model, including the advection and diffusion terms as ocean physical processes. This three-dimensional system was solved by finite differential method. The horizontal oceanic area is 100 km x 100 km referring to extention of the Toyama Bay and the resolution is 2km x 2km. For the model calculation, we employed a horizontal diffusive coefficient of 10 (m^2/s) and performed a cyclonic circulation as flow fields. Also vertical diffusive coefficients are in the range of 10^{-5} to 10^{-2}(m^2/s).
The experiments are carried out for macro and micro plankton, and several values of grazing rate coefficient showing a relationship between the predictor-pray of planktons as the ecosystem parameters.
In this numerical experiment, assuming the inflow of nutrient from rivers, we set up a situation where the concentration of nutrient increases from below the model area and analyse the transition.
We also analyzed by using COMS-GOCI satellite image to understand development of chlorophyll-a pattern in the actual situation in the Toyama Bay and to compare it with numerical experiment.
The data is from April to September of 2010 to 2014 and data from April to October 1, 2015 (lacking only for July 2012).
In the numerical experiment without vertical diffusion, the counter-clockwise spiral pattern was formed in all zooplankton parameter. This pattern gradually collapsed, and then the amount of phytoplankton in the model area changed uniformly(cf. Fig. 2). After that, a spiral pattern was appeared again only in micro zooplankton parameter.
The counterclockwise spiral pattern in the surface layer in the three-dimensional model with the vertical diffusion.
The concentration of phytoplankton was lower in the three-dimensioal case than that in the two-dimensional case, however, because the nutrient supplied on the surface layer was carried to the deep layer by the vertical mixing.
It was found there were cases where the spiral pattern was formed to the lowest layer and cases where it was not formed, depending on the zooplankton parameters and the magnitude of vertical diffusion.
From these experiments, the formation of the spiral pattern in Toyama Bay is assumed nutrient supplied from a river is transferred to a counterclockwise flow field, and then phytoplankton consume its nutrient.
We found that for the abundant nutrient in the bay, the spiral pattern was formed with active interactions of predator-prey between plankton.
In satellite image analysis, chlorophyll-a concentration distribution in Toyama Bay was classified into 4 patterns. : firstly high concentration in the offshore area, secondly high concentration on the coast, thirdly high concentration part developed from near Kurobe river estuary toward Toyama Bay, fourthly spiral

pattern.
For the fourth spiral pattern, we showed the possibility to explain the mechanism of the formation in the numerical experiment.
Moreover, for the formation of a spiral pattern, we suggest that spring water in the Kurobe River with the rich nutrient are carried in counterclockwise circulation field in the Toyama Bay. Furthermore we plan to investigate the above described items in three-dimensional model research.

Keywords: chlorophyll-a, ecosystem model, Toyama Bay, two dimensional pattern, Vertical mixing

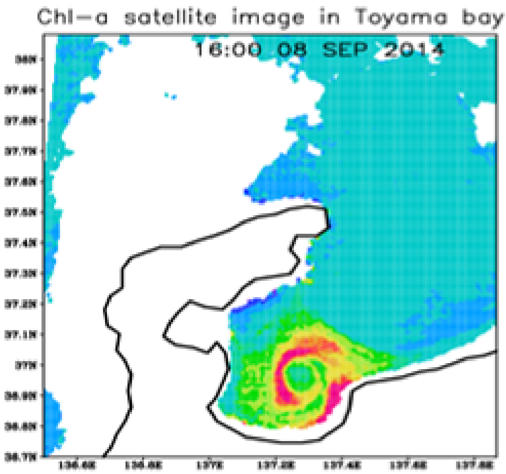

Figure.1
Chlorophyll-a concentration distribution in COMS-GOCI satellite.

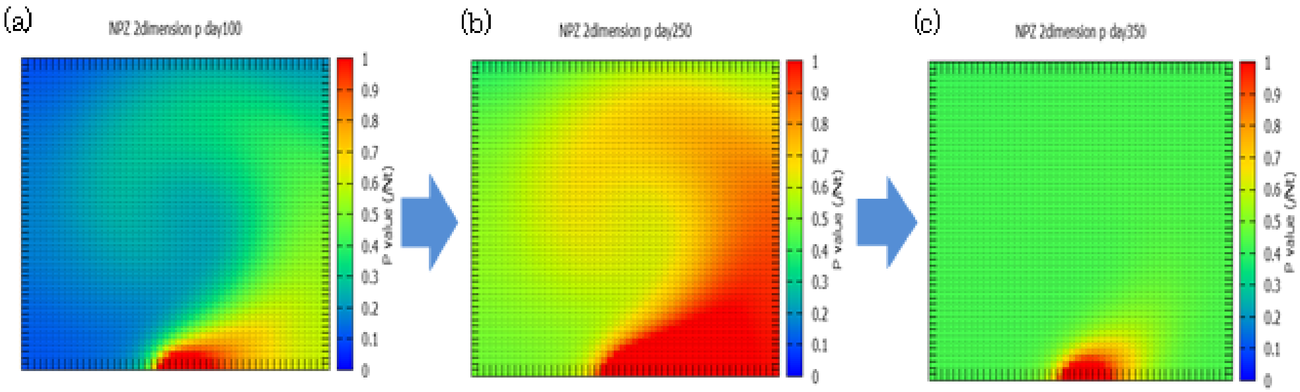

Figure.2
Transition of the phytoplankton concentration distribution in numerical experiment.
(a) Distribution of 100 days
(b) Distribution of 250 days
(c) Distribution of 350 days