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

