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Spatial distribution maps of real-time ocean observation platforms and sensors in Japanese waters

Kotaro Tanaka [a,*], Mengyao Zhu [a], Kohei Miyaji [b], Tadayuki Kurokawa [b], Tomonari Akamatsu [a]

[a] *Ocean Policy Research Institute of the Sasakawa Peace Foundation, Tokyo, Japan*
[b] *IDEA Consultants, Inc., Tokyo, Japan*

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ABSTRACT

Ocean observations are required to provide timely evidence of facts about the ocean in order to evaluate the sustainable management of biodiversity, climate change, fisheries, mineral resources, tourism, and any other anthropogenic activities that support blue economy policymaking. In Japan, this is particularly crucial given that it is an islandic country stretching from north to south, thereby having a diverse coastal environment. Although tremendous efforts towards ocean observations have been made, coordination among sectors is not always sufficient, which prevented availing the comprehensive capacity of ocean observation. In this study, the existing observation platforms and installed sensors, particularly fixed platforms that enable real-time data transmission, were reviewed, and the spatial distribution of them was investigated. It was confirmed that a large number of observation networks cover Japanese waters; however, many of those platforms were used for single purpose, and the spatial coverage was still considerably limited for some sensors, such as salinity, dissolved oxygen, and chlorophyll a. It must be noted that this study intentionally limited the data sources of platforms/sensors to the disclosed data on public reports and/or websites, in order to raise a discussion about information disclosure of observation efforts, conducted by numerous stakeholders. Based on this information, we recommend extending the capacity of ocean observation by utilizing existing platforms rather than constructing new platforms, in order to enhance cost-effectiveness.

1. Introduction

Multiple challenges to the ocean, such as ocean warming, sea level rise, marine pollution, degradation of fisheries resources, and decreasing biodiversity, have emerged. Providing baseline information on the current status of the ocean contributes to global and regional policy-making. Consequently, ocean observation is also connected to blue economy, which is the sustainable use of ocean resources for economic growth and improved livelihoods and jobs while preserving the health of the ocean ecosystem [1], as it provides timely evidence of regulation or promotion of marine industry, tourism, and fisheries [2]. The United Nations (UN) proclaimed a Decade of Ocean Science for Sustainable Development, which was officially initiated in 2021 [3], envisioning “to develop scientific knowledge, build infrastructure and foster relationships for a sustainable and healthy ocean”. The Decade of Ocean initiative is a global contribution to the implementation of the Sustainable Development Goals (SDGs), including SDG 14, which aims to conserve and sustainably manage ocean and marine research [4]. Sustained ocean observations and forecasts play a key role in this context [2]. Recently, maritime domain awareness (MDA) has been used, not only in the context of security, but also for the effective understanding of anything associated with the maritime domain that could impact safety, the economy, or the environment. Since MDA consists of various kinds of information, improving MDA is one of the keys for providing baseline evidence for maritime management and policy-making to deal with the challenges mentioned above. MDA should be enhanced by expanding the current capacity of ocean monitoring. The capacity can be expanded, not only by increasing the number of data inputs, but also by integrating existing data.

Globally, multiple initiatives have been conceptualized and operations have expanded to increase our capacity for ocean observation. The Global Ocean Observation System (GOOS), which is led by the Intergovernmental Oceanographic Commission (IOC) of UNESCO, is a program set up to lead and support the development of international, regional, and national ocean observing programs, as well as aid governments, research organizations, and individual scientists. Other than

* Corresponding author.
E-mail address: k-tanaka@spf.or.jp (K. Tanaka).

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that, there are numerous initiatives of ocean observation, such as the Copernicus Marine Environment Monitoring Service (CMEMS) and The European Marine Observation and Data Network (EMODnet) in Europe, the Integrated Ocean Observing System (IOOS) in the United States, the GOOS Regional Alliance for the Upper Southwest and Tropical Atlantic (OCEATLAN), and the Southeast Asian Global Ocean Observing System (SEAGOOS) [5–11]. Many other GOOS regional alliances identify, enable, and develop sustained GOOS ocean monitoring and services to meet regional and national priorities, aligning the global goals of GOOS with the need for services and products satisfying local requirements [12].

Japan, a country surrounded by oceans on all sides, has jurisdiction over one of the largest ocean areas in the world corresponding to approximately twelve times the national land area [13]. Given numerous stakeholders from various fields are involved in ocean governance, enacting measures requires comprehensive coordination at the government level as well as mutual adjustment among individual measures. Therefore, the Basic Act on Ocean Policy was enacted in July 2007 to comprehensively and systematically promote the full range of measures relating to the ocean with the aim of realizing Japan as a new maritime nation [13]. Subsequently, the First Basic Plan on Ocean Policy was approved by the Cabinet in 2008 to proceed each measure effectively and then revised almost every 5 years. According to the Third Basic Plan of Ocean Policy, which is the latest version of the Basic Plan on Ocean Policy as of now, "changes in the maintenance and protection of the marine environment", e.g. Climate change, ocean acidification, degradation of marine biodiversity and microplastics, is recognized as one of the current situations in Japanese waters [13]. In the same version, the importance of ocean observation is also acknowledged in the context of the conservation of marine environment, strengthening the capacity for Maritime Domain Awareness (MDA), and promotion of research and development as to maritime research and marine science & technology [13].

As an example to highlight the importance of ocean observation in Japan, Seto Inland Sea, the largest inland sea in Japan and one of the world's prominent inland seas (Fig. 1), experienced severe deterioration in the water and bottom qualities occurred from 1950 s to 1970 s, because of the intensive industrialization in the coastal plains by the post-war economic growth in Japan [14]. Accordingly, since 1979, the Japanese government has regulated several effluents, and the water quality improved and the concentrations of dissolved inorganic nitrogen and PO4-P decreased rapidly in the late 1970 s to early 1980 s [15]. However, this decrease has caused damage such as the discoloration of cultured seaweed, or *nori*, since the 2000 s [16]. In addition, the amount of fish catches in the SIS continues to decline, suggesting that the fishery productivity there is deteriorating [17]. This history tells us the importance of conducting continuous ocean observation and adjusting policy direction based on scientific knowledge accordingly or proactively.

Regarding real-time ocean observation platforms, many of the discussions in Japan seem to focus on enhancing availability, application, sharing, or accumulation of ocean data derived from existing platforms, rather than physically expanding the number of platforms [13]. This might relate to the current situation of funding to ocean science in Japan. According to Global Ocean Science Report 2020 issued by IOC-UNESCO, the growth rates of ocean science expenditure in Japan between 2013 and 2017 is less than −15%, (from some US$ 1.4 billion to slightly less than US$ 600 million) which is the largest decrease rate among the respondent countries in this analysis [18]. Given this situation, considering cost-effectiveness is essential to balance expanding the capacity of ocean observation and limited financial resource.

Japan contributes to enriching GOOS data (meteorological observations, oceanographic measures, etc.) with the work of several organizations including the Japan Meteorological Agency (JMA), the Japan Coast Guard (JCG), the Japan Oceanographic Data Center (JODC), the Japan Marine Science and Technology Centre (JAMSTEC), and Japan Aerospace Exploration Agency (JAXA). For instance, MDA Situational Indication Linkages (MSIL) is an information system that provides instant access to ocean geospatial information collected by government agencies and relevant organizations under the overall inter-ministerial coordination by the National Ocean Policy Secretariat [19]. The Global Oceanographic Data Center (GODAC) serves as a hub for accumulating and disseminating various research data held by JAMSTEC [20]. Obviously, in addition to these initiatives, countless ocean observations were carried out at national, regional, and local scales by different authorities, institutions, or individual researchers. However, coordination among industry, government, academia, and the private sector in the field of ocean science in Japan is not always sufficient, and policy making and budget allocation tend to be carried out in a line with the purposes of each authority and project [21].

On the land, along with the rapid development of information technologies, Japanese government advocated the concept "Society 5.0", which aims at creating a society where people can resolve various social challenges by incorporating the innovations of the fourth industrial revolution (e.g. Internet of Things, big data, artificial intelligence, robot and the sharing economy) into every industry and social life [22]. In Society 5.0, numerous sensors are distributed to monitor the movement of people, vehicles, public transportation, commodities, and infections. Along with the development of computing hardware and artificial intelligence techniques to handle big data, huge amounts of information collected by different sensors are integrated and analyzed for both economic advancement and resolution of social problems. The application covers a wide variety of topics, from marketing to medical care. While Society 5.0 is steadily developing on land, the speed of development in the ocean is relatively slow. One of the main reasons for this is that, as described above, there is still a barrier in the way of cooperation among authorities carrying out ocean observations. Since most of them were established by independent projects and are thus operated by different authorities, data integration has not always been sufficiently carried out, although each of them continues to accumulate substantial data. To proceed with Society 5.0 in the ocean, these data are expected to be integrated and analyzed for further applications by creating transdisciplinary information flow.

Society 5.0 in the ocean, which includes information from the sea surface, water column, and seafloor collected and utilized via real-time transmission routes, such as satellites or submarine cables, is awaited. To achieve this, understanding the current capacity of ocean observation, which would provide baseline information to support policy implementation, is required. For instance, finding the spatial leakage of ocean observation networks would be essential to optimize the investment for building additional observation infrastructure. Furthermore, it is suspected that only a single sensor is often installed on a platform because of the single-purpose observation program. Given that the budget for ocean observation is limited, it would be more cost effective to install additional sensors on existing platforms and promoting multimodal use of sensors by cutting the investments to construct new infrastructure from scratch. From those reasons, comprehensive review of existing platforms and installed sensors is required, but little has been carried out in Japan so far.

The objective of this study is to understand the current capacity of ocean observation in Japan by reviewing existing platforms/sensors and visualizing the spatial distribution of them in Japanese waters. As described above, the importance of ocean observation and integration of collected data is already acknowledged by Japanese government. This study is expected to encompass the concrete measures of those direction, e.g. "what" and "where" of additional sensor expansion in future. In particular, this study limited its scope in two aspects: (1) platforms/sensors that conduct autonomous observation, mainly for ocean physics and real-time data transmission, are focused on, although manual observation i.e., water sampling and/or ship observation, is indispensable for examining chemical and biological information that is difficult to measure using sensors. (2) This study was based only on the disclosed

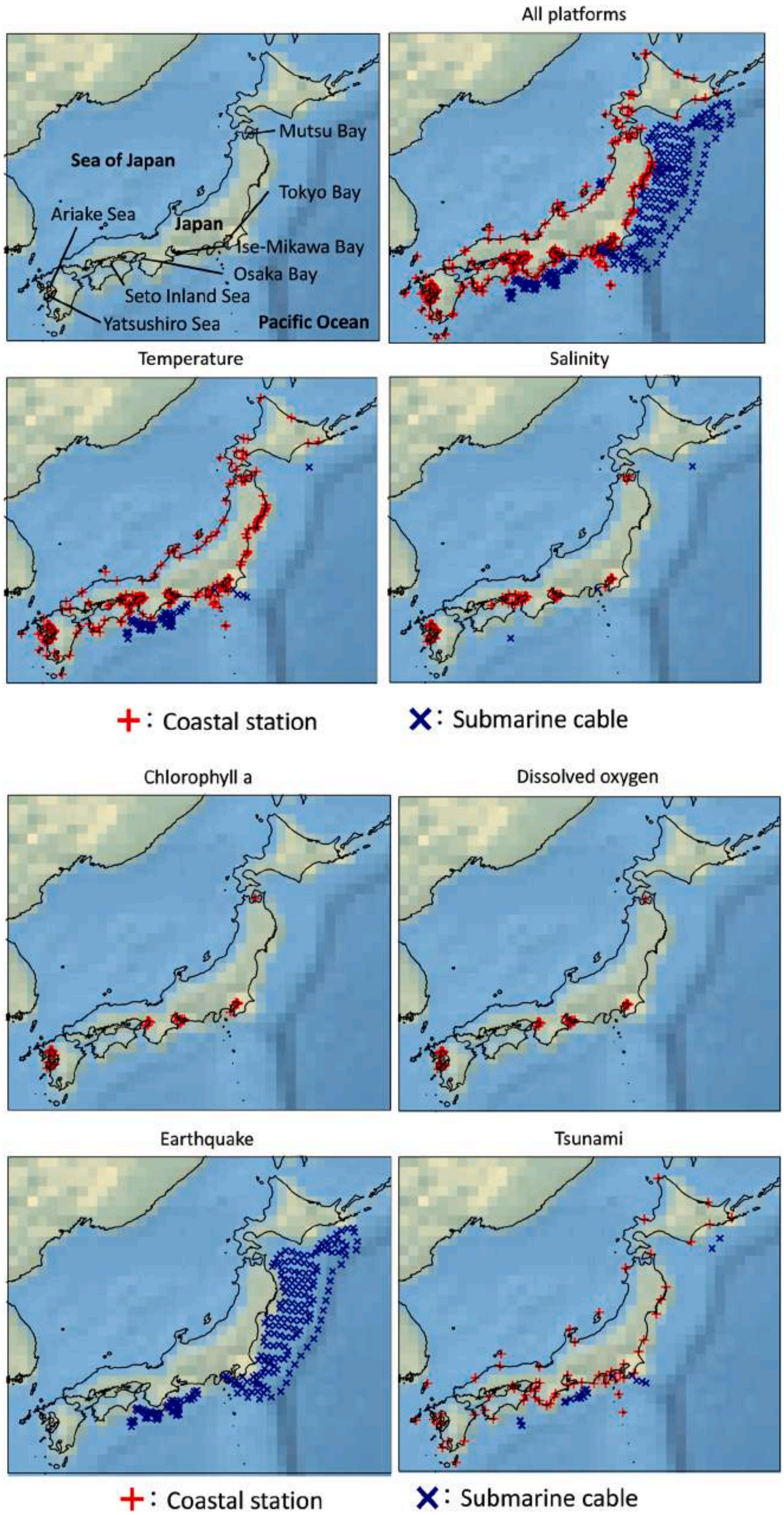

Fig. 1. The distribution of fixed observation platforms along the coastline of Japan. Each figure shows the platforms of different sensors. The red symbol + represents point observation, and blue symbol X represents submarine cable. (For interpretation of the references to colour in this figure, the reader is referred to the web version of this article.)

information available on the public reports and/or websites of projects or authorities, and thus, further inquiry about observation platforms/sensors was not conducted intentionally. This is because raising discussions about information disclosure was another key purpose of this study.

2. Materials and methods

As introduced above, this study took Japan as a case study, considering that its marine environment hugely diverse and thus the persistent ocean observation is essential to realize the science-based management. We have commenced drafting an overview of the current status of platforms and sensors that are under operation in Japanese waters, except southwestern islands, based on "The report of ocean survey 2020" issued by the Cabinet Office of Japan [23]. This source summarizes the list of observatories operated by government agencies. Further, additional searches were conducted using the names of observation devices or parameters as search queries to complement them. This study focuses on disclosed information; therefore, platforms/sensors that are not publicly open, on either the public report or websites, were not included. It seemed that not all information about platforms/sensors was disclosed online. We deliberately refrained from contacting each authorities to obtain further information, to clarify our proposition that we based on disclosed information and thus encourage authorities to disclose it if it is allowed in the sense of security or other sensitive reasons. The website URLs of each observation platform were listed up in the supplementary material as further references of the infrastructures' detail, although many of those websites are only written in Japanese. This would be another challenge to be considered in future.

For the purpose of this study, sensors refer to devices, modules, or machines used for ocean observation, which are installed or mounted, and platforms refer to equipment or facilities, which are generally fixed at specific positions. Thus, there are some cases in which multiple sensors are installed on the same platform. Regarding platforms, point platforms were focused on in this study because they are operated on stable and long-term basis, and the data is continuously obtained online. They are generally deployed in near-shore areas, where the electricity supply and data transmission are relatively inexpensive. Continuous water quality observations in Tokyo Bay is one of the examples of point platforms in Japan [24]. Submarine cables also belong to this point observation in this study, since it consists of multiple nodes connected in line. The main targets of observation of these platforms are earthquakes and tsunamis, using accelerometers and pressure sensors.

This study was focused on real-time data-collecting platforms in water. Various platforms and sensors that did not satisfy this scope, were not included in this study. For example, water sampling, float, ship, drifting buoys and satellite observations were omitted from the scope of this study, even though there is no doubt that they play key roles in ocean observations. This is because they are not always operated either in an autonomous or semi-permanent manner, or the data transmission and electricity supply are not always available in real time. Satellites are generally unable to observe subsurface phenomena, except for the results supported by the oceanographic model. The temporal and spatial coverage of these other platforms deserve further analysis in other studies to shed light on their gaps, in the same manner as in this study.

The parameters, which are observed by sensors installed on each platform, were surveyed by searching the disclosed information about platforms. The deployed locations of the platforms were also extracted to visualize their spatial distributions.

In this study, sea temperature, salinity, chlorophyll a, dissolved oxygen (DO), earthquakes, and tsunamis were selected as representative sensors (Table 1). The detailed sensing system to measure these parameters is not described here because it is beyond the scope of this study. All parameters, except earthquakes and tsunamis, are important indices of water quality and can be considered for a variety of simulations and analyses. Temperature (sea surface and subsurface), salinity

Table 1
Ocean observation parameters and their relevant ocean challenges.

Parameters	Relevant ocean challenges
Temperature	Ocean warming, Sea level rise, Ocean acidification, Eutrophication, Red tide, Hypoxia, Seagrass bed degradation, Coral reef bleaching
Salinity	Ocean acidification, Eutrophication, Red tide, Hypoxia, Seagrass bed degradation, Coral reef bleaching
Chlorophyll a	Ocean acidification, Red tide, Hypoxia, Seagrass bed degradation, Coral reef bleaching
Dissolved Oxygen (DO)	Ocean acidification, Red tide, Hypoxia, Seagrass bed degradation, Coral reef bleaching
Earthquake	Natural disaster
Tsunami	Natural disaster

(sea surface and subsurface), and oxygen are listed as physical and biochemical Essential Ocean Variables (EOVs), which are classified by GOOS expert panels as variables that maximize the utility of oceanic data with balanced relevance to climate and ocean health, feasibility, and cost effectiveness [25,26]. Chlorophyll a is not explicitly listed, but is indirectly included in the ┼phytoplankton biomass and diversity┼ of biological and ecosystem groups [27].

Sea temperature, which includes the sea surface and subsurface, is an essential parameter for monitoring ocean warming. Ocean warming may potentially cause multiple negative impacts to the environment, such as sea level rise, eutrophication, coral bleaching, and a decrease in biodiversity; thus, it needs to be monitored in the long term and consistently for future predictions and assessment. Generally, the sensors of water temperature measure the change in electrical resistance with a metal or thermistor. Salinity is also one of the fundamental parameters that can be used for many aspects of simulations, from fish stock assessment to acoustic tomography. Salinity is calculated from electrical conductivity, temperature, and pressure, as seawater is an electrolyte aqueous solution. Chlorophyll a is a photosynthetic pigment of phytoplankton, and thus can be used as an index of the biomass and location of phytoplankton. It is an important measure to monitor the chemical and biological conditions of the ocean, for example, the eutrophication or degradation of seagrass beds. The concentration of chlorophyll a was measured using fluorometric methods. DO is a relative measure of the concentration of oxygen dissolved in sea water as a proportion of the maximal concentration that can be dissolved in that medium. It plays a key role in monitoring water quality, but is particularly crucial for hypoxia, which causes damage to fisheries and aquaculture. There are multiple methods to measure DO, but in the case of automatic sensing, electrochemical sensors, also known as membrane-covered DO sensors, are generally adopted. A unique feature of the Japanese environment is that it suffers frequent threat of earthquakes and subsequent tsunamis. Thus, observing earthquakes and tsunamis, in addition to the EOVs introduced above, is particularly important for the prediction, detection, and damage reduction of disasters. Submarine seismometer and pressure gauge, which are pressure and acceleration sensors, are employed to observe small to large earthquakes, slow slip events by seafloor pressure, and tsunamis. Their frequency bands are typically low, ranging from less than 1–100 Hz, although the exact band varies among the sensors [28,29].

After the accumulation of the data, the correspondence matrix of observation platforms and installed sensors was created. Furthermore, the locations of the platforms were visualized per sensors on a map of Japan, in order to visually understand their spatial distribution. For platforms where exact coordinates were not described, map images of deployment locations were opened on a website, and approximate locations were extracted and plotted on the map. Data processing and visualization were performed using custom-made programs of Python. "Cartopy" library was used to create spatial distribution map. The precision and data sampling frequency of the sensors were also surveyed, and relevant statistics, i.e. mean, standard deviation, minimum and maximum were calculated for those which had sufficient number of data.

3. Results

In total, 569 platforms were identified with the information of mounted sensors by the review of this study, and their locations were extracted and plotted on the map of Japan (Fig. 1). The information of identified observation platforms, including authorities, locations (latitude and longitude), installed sensors, precision and data sampling frequency and reference URLs, was listed in the supplementary material (SI 1, SI 2).

The results show that many ocean observation platforms are under operation, such that the entire coastline of Japan is roughly covered by them. The number of sea temperature sensors was the highest among the focused sensors (325), and the second was the earthquake (218). The number of sensors used to measure salinity, chlorophyll a, DO, and tsunami were much less than those used for the measurement of temperature and earthquakes, 85, 45, 43, and 95, respectively (Fig. 2). This indicates that large number of platforms are used for single purpose, mostly to monitor temperature (Fig. 1, SI 1). The distributions of sensors, except tsunami sensors, are limited to certain bays, for example, Mutsu Bay, Tokyo Bay, Ise-Mikawa Bay, Osaka Bay, Ariake Sea, and Yatsushiro Sea (Fig. 1). Tsunami sensors are scattered along the coastline of Japan, including those that are mounted on the submarine cable. Less sensors are allocated to the Sea of Japan side than the Pacific Ocean side. The precision and data sampling frequency varied within each parameter, although not all of those information was disclosed online (Table 2).

4. Discussion

This study reviewed the existing ocean observation platforms and installed sensors, and visualized the spatial distribution of platforms, focusing on the several sensors that enable continuous and real-time observations in Japanese waters. Few studies have been conducted to review their actual circumstances from a comprehensive perspective, particularly in Japan. The results showed that there is a broad network of ocean observation platforms covering the coastline of Japan's main island. However, many of the sensors are single-purpose, and do not seem to be equally allocated along the Japanese coastline (Fig. 1, SI 1). Even for the temperature sensors, which have the highest number among all sensors considered in this study, the number of observation platforms showed clear differences between the sides of Pacific Ocean and the Sea of Japan, wherein the former had much more than the latter (Fig. 1). It should be noted that counting the exact number is not feasible because the border between the two sides is not concisely defined. For other parameters, such as salinity, chlorophyll, and DO, the observation platforms are highly concentrated in specific areas, especially in large bays, such as Tokyo, Osaka, and Ise-Mikawa bays. submarine cables are deployed on the Pacific Ocean side, except for one on the Sea of Japan side. This is because the plate boundaries on the Pacific side have the potential to cause devastating earthquake disasters.

Based on this limitation of ocean observation for some parameters, extensions of sensor deployments will be expected in the future, as well as the integration of collected data. Considering that numerous observation platforms have already been under operation in most coastal areas, and budgets for ocean observation are limited, it is suggested that utilizing existing platforms is an effective way. In that sense, the outcome of this study supports to consider "what" and "where" to install additional sensors. A few examples of ocean challenges in which the extension of observation sensors is effective and necessary are discussed below.

Red tides are harmful algal blooms occurring along coastal regions, which result from large concentrations of aquatic microorganisms, such as protozoans and unicellular algae [30]. In Japan, red tides rapidly increased during the period of high economic growth from the 1960 s, especially in the area of the Seto Inland Sea, the Tokyo Bay, and coastal areas of Kyushu etc. As reported, a single red tide can cause an economic loss valued greater than 1 billion JPY in Japan [31]. Since the prediction of red tide occurrence is essential to enact damage reduction measures for the aquaculture industry, such as moving fish cages to harmless areas or early fish catchment, a large number of studies have been conducted to predict its occurrence by monitoring physical and chemical conditions, such as water temperature, salinity, chlorophyll a, DO, and pH [32]. Accumulating the time series of the information in a certain area was demonstrated to be important for the prediction [32]. Furthermore, it has been reported that red tides do not always occur and grow at the same bays or estuaries, but sometimes arise at a certain bay or estuary, grow up with moving by the current, and finally cause huge damage at a different bay [33]. In this sense, monitoring ocean conditions on a large spatial scale, even outside a bay or estuary where the aquaculture is carried out, and integrating the obtained data is necessary for the prediction, mitigation, and understanding of the mechanism of its occurrence.

This was the case with oxygen depletion or hypoxia. In hypoxia DO is reduced in concentration to a point where it is detrimental to aquatic organisms living in the system [34]. Even though oxygen depletion itself is measured by DO, it can be caused by the interaction of several parameters, such as the red tide [35]. In that sense, parameters other than DO, such as salinity and chlorophyll a, should be monitored to predict the occurrence of oxygen depletion as it could cause huge damage to

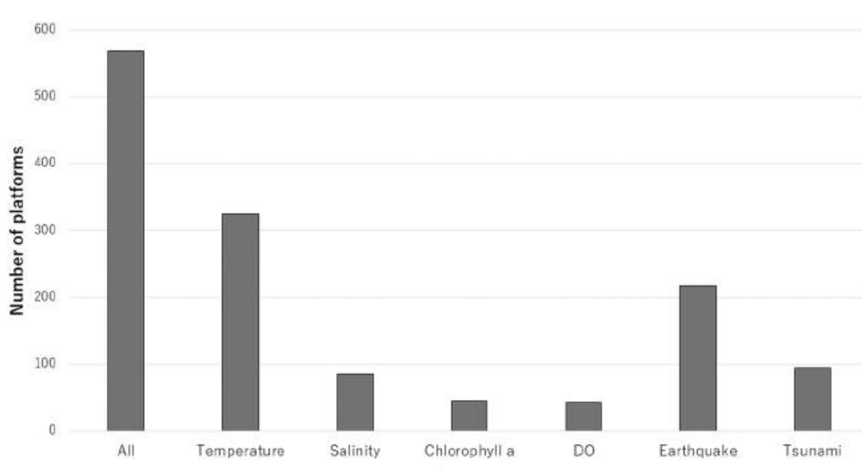

Fig. 2. The number of platforms that each sensor is installed. Note that for some cases, several sensors are installed on one platform.

Table 2
The statistics of precision and data sampling frequency for each parameter. NA represents that the number of available information was too small to calculate statistics.

	Mean precision (± SD)	Min precision	Max precision	Mean sampling frequency (± SD) times / hour	Min sampling frequency times / hour	Max sampling frequency times / hour
Temperature	0.06 ± 0.06 ℃	0.001 ℃	0.15 ℃	1.73 ± 1.53	1	6
Salinity	0.08 ± 0.03	0.05	0.1	1.16 ± 0.46	1	3
Chlorophyll a	1.3 ± 0.5%	1%	2%	0.98 ± 0.09	0.5	1
DO	NA	NA	NA	1.14 ± 0.35	1	2
Earthquake	NA	NA	NA	NA	NA	NA
Tsunami	NA	NA	NA	NA	NA	NA

fisheries and aquaculture.

Even though earthquake sensing networks largely cover the side of the Pacific Ocean, there is still the potential to enhance their capacity for ocean observation. Expanding the frequency range of accelerometer and hydrophone, which is available at the on-land station in real time, might be an effective strategy. Passive acoustic monitoring techniques have the potential to help explore the distribution, migration, and abundance of vocalizing animals, and to assess the large-scale influence of artificial noise on marine organisms and ecosystems [36,37]. Real-time acoustic monitoring networks have been used in some countries to observe the presence/absence or density of vocalizing marine animals and to assess the impact of anthropological noise on them [38]. Since only a few of these networks operate in Japan, establishing more of such networks would be meaningful for monitoring the recent increase in underwater noise. In that sense, the submarine cables might play a critical role because they enable real-time data transmission and cover the migration route of some baleen whales [39]. However, as described above, the frequency band of seismic pressure sensors installed on submarine cables in Japan typically ranges from 1 H to 100 Hz [11,12]. This is reasonable because the frequency of earthquakes and tsunamis is typically very low and within this range. On the other hand, a large part of the frequency ranges of sounds produced by marine organisms in this area are generally beyond this range. For instance, the major energy of the sound produced by silver croakers (*Pennahia argentata*), which is an important fishery resource, is typically within 100–1000 Hz [40]. It has been reported that some species of baleen whales migrate offshore of the Pacific Ocean side in Japan, such as fin whale (*Balaenoptera physalus*) and humpback whale (*Megaptera novaeangliae*) [39,41]. Although the frequency range of fin whale vocalizations is within the current range, and thus it has been observed by submarine seismic observation systems [41,42], vocalizations of many baleen whales, including humpback whales, are typically higher than that, for example, 500–5000 Hz [43]. Furthermore, vessels, including small fishing boats and large tankers, are also important objects to be monitored by the sounds produced by them. Broadening the frequency range of the hydrophones up to 5000 Hz would be effective for monitoring biological and anthropological sounds [44]. Installing additional hydrophones to a few observation nodes is recommended to determine the cost-effectiveness of frequency extension. Given that, as of the date of this paper, another submarine cable, N-net, is being planned to be constructed on the east side of Kyusyu, the third largest island of Japan [45]. The side of the Pacific Ocean of Japan is expected to be roughly covered by submarine cable network in near future. It would be worthwhile to consider extending the capacity of the sensors in addition to the original purpose.

Constructing new platforms will be one of the ways to extend the ocean observation networks along the Japanese coastline, but it requires huge investment. Instead, we recommend attaching additional sensors to existing platforms as it is more cost-effective than constructing new observation platforms from scratch, and as a large number of platforms are already under operation in many parts of Japanese waters. Generally, the costs of building a system for electricity supply and data transmission are estimated to require more investment than the cost of new sensors and their attachment. This is particularly crucial in the case of submarine cables. The construction and deployment of new submarine cables requires a huge amount of investment, that is, surveys of detailed bathymetric features, ship operations to cut trenches and lay cables on the sea floor, and building a new on-land station if needed. On the other hand, for attachment or replacement of sensors, it would be done in a similar manner to cable repair; catching the cable with a grapple, lifting up the node, replacing the sensor, and sinking it down again. The data transmission protocol has to be modified in accordance with the change of data format, and the labor for maintenance is still required; however, compared to constructing them from scratch, it would cost relatively less.

There is no doubt that actual cost and benefit analysis of ocean observation in Japan is very important to consolidate the argument above, but it is considered that such analysis is beyond the scope of this study at the moment. One reason is that this study aimed to visualize the current capacity of ocean observation in Japanese waters, which serves as part of the baseline information of a strategy planning toward expanding the capacity in future. Another reason is that, while this study stands on the public data, which is disclosed on the websites of the institutions and authorities, cost information (initial cost and running cost) was hardly found in disclosed information as far as we searched. Furthermore, the economic benefit from ocean observations is still hindered by the lack of direct estimates of the value of ocean data for projected applications [46]. Cost and benefit analysis deserves another study to achieve practical policy making.

How many new sensors are needed on a specific parameter would be another information required to plan concrete strategies. Sufficient numbers of sensors are assumed to vary among locations and parameters, given the complexity of Japanese coastline. To assess this, comparison between simulation results and ground truth data collected in situ would be required. If the gap between them is significantly large, we could assume that additional sensor(s) need to be installed. In that sense, ocean observation from mobile platforms, e.g. research vessels, floats or remotely operated vessels, play an important role to provide ground truth and information about spatial variation of each parameters.

There was a variation of the precision and data sampling frequency even within each parameter (Table 2). For example, the precision of temperature varies from 0.001 ℃ to 0.15 ℃, which is 150 times difference. Given required precision and data sampling frequency depend on the purpose of analysis, sufficient values of them need to be assessed separately, as well as the number of sensors described above.

This study took Japan as a case study. Considering Japanese archipelago shows huge environmental variations within its approximately 3000 kilometers of length from subarctic north to subtropical south, effectively distributing the observation network will be particularly essential to enhance the scientific understanding of changing ocean, in order to take evidence-based adjustment and mitigation measures in national and sub-regional level. The challenges in ocean observation that Japan faces are assumed to be common among countries which has jurisdiction over large ocean area, and thus the countermeasures, namely effective expansion of current observation capacity and data sharing, would be more or less similar. This case study may serve as a reference to collect baseline information for considering a policy to deal with such challenges in those countries and regions.

A limitation of this study is that there is a non-negligible possibility that numerous observation platforms do not fall under the coverage of this study. However, it is also true that a considerable amount of information about platforms and sensors is not disclosed to end users, even though they have been under operation for years and have provided valuable data. Another purpose of this study is to list existing observation platforms based on open data to encourage data disclosure and sharing if they are not classified. Therefore, this study only reviewed information that is available online and did not inquire further information on platforms, for example, locations or installed sensors, to researchers or institutions. Regarding data disclosure, it is understandable that some of the observation systems or data obtained by them are classified for security reasons or other sensitive matters. For some data that required huge investment to observe, it might be difficult to open them free of cost considering the expense. Even though, for the policymakers (who are the "end users" of this data) and the strategy planners, this information of observation activities or systems, and not necessarily the data itself, will be useful to consider investment allocation. Information disclosure should be paid attention to in the process of system development. In addition, this study focused on the point platforms, among other platforms, such as ships, floats, and satellite platforms. These platforms also play a key role in ocean observations. Visualizing the spatial and temporal coverage of these platforms is expected in order to consider the investment strategy of their expansion.

As a future prospect, there should be the development of a web-GIS system to visualize the locations of observation platforms/sensors on a map, which is partially implemented in existing platforms such as MSIL, as well as detailed information of sensors such as precision or data sampling frequency. It would help both scientists and non-scientists understand the current ability of ocean observations in this country. Researchers can visit the website to see if any observation platforms are under operation in an area of interest, and if the data is available or not. They might be able to omit time and labor to collect data on sites if the resolution and accuracy meet their requirements and data is available, regardless of whether it is for free or not, and then use such data for their own purpose. For policymakers, it would be valuable to understand the distribution of observation effort, which could be used as baseline information to consider the effective allocation of investment for reinforcement of ocean observation. Integration of oceanic data and the creation of ocean big data will also be expected. Currently, the data are collected by researchers or institutions for their own purposes in many cases. Even though part of them are available on the website of each institution or public database such as the JODC or MSIL, they are allocated in different places, and the data formats are not quite united. This prevents users from collecting and analyzing them for their own purposes, since such format inconsistency requires a long time for data preprocessing. To overcome this problem, the development of an ocean big data center, which makes data available in the united format, is expected. In the Ocean Policy Research Institute (OPRI), Japan, several studies are being conducted on this data center development and integrated utilization of platforms/sensors, as well as the proposed study. As per the results of this study, a visualization of platforms and sensors would be the first step towards data integration.

So far, two issues for the Japanese government have been discussed; (1) to further utilize the current platforms; and (2) to integrate data/information being extracted from different parameters or platforms, given that they are built and operated by different actors. To consider the priority of those two issues might be constructive for policy prescription. It seems to be clear that even if the first issue is addressed, the second remains a problem. On the other hand, by integrating data/information, the necessity and requirement of utilizing the current platforms would be more surfaced and clarified. Proceeding the integration of data/information is expected to contribute to enhancing the capacity of ocean observation, and thus the "gap" between the ideal and current coverage might be understood. In that regard, tackling the second issue might be slightly prioritized than the first one, although proceeding both of them in parallel is ideal.

5. Conclusion

This study discussed the importance of further utilizing the existing observation platforms in Japan's maritime domain. Ocean-related physical, chemical and ecological data is the basis for modern maritime governance, blue economy policy making and monitoring of the climate change, and is acquired through platforms and sensors. In this regard, the platforms of ocean observation in Japan are not always operated together and reciprocally among various sectors, organizations, and projects, rendering integration a desirable policy goal. Based on disclosed information, this study focused on six types of platforms and sensors (temperature, salinity, chlorophyll a, dissolved oxygen, earthquake, and tsunami) and conducts a survey to identify their geographical distribution. A visualization of these platforms suggested that, although there are considerable amount of platforms which were already implemented in the waters surrounding Japan, they are not evenly allocated. It is therefore recommended that, to better tackle issues such as red tides and the enhancement of acoustic monitoring networks, the current platforms or the networks thereof should be extended. Moreover, from a cost-effectiveness perspective, attaching new sensors to the existing platforms is a more reasonable option than building new ones, as well as integrating the collected data to establish ocean big data. Additional cost and benefit analysis of ocean observation is expected to provide an evidence of the recommendation of this study. The coverage of this study might not be flawless, but it would provide part of the baseline information to consider future investment strategy for expanding ocean observation capacity.

Even though this study focused on Japan as a case study, the framework itself can be applicable to any other countries or regions. We hereby recommend the procedure to consider strategy of expanding ocean observation capacity as follows.

1. Review the distribution and characteristics of existing ocean observation platforms in the target country or region.
2. Review the type and precision of sensors which are installed to those platforms
3. Create the matrix (and corresponding figure for visual understanding) of platforms and installed sensors as shown in Fig. 1 and SI 1.
4. Choose representative platforms which seems to be suitable for additional sensor installation
5. Even if installing additional sensors to existing platforms is challenging because of technical reason, this study can be referred when new platforms are constructed in future.
6. As a future direction, consider establishing the dedicated institution to oversee ocean observation and collected data in a country or region.

CRediT authorship contribution statement

Kotaro Tanaka: Formal analysis, Data curation, Writing – original draft **Mengyao Zhu**: Data curation, Writing – review & editing, **Kohei Miyaji**: Investigation. **Tadayuki Kurokawa**, Methodology, Investigation, **Tomonari Akamatsu:** Conceptualization, Writing – review & editing, Supervision.

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Declaration of interest

None.

Supplementary materials

SI 1: The matrix of existing real-time ocean observation platforms and installed sensors in Japan. Fig. 1 was visualized based on the information listed here with the coordinates in SI 2.

SI 2:The collected information about platforms and sensors, i.e. name of platforms and managing authorities, location (latitude and longitude), installed sensors, precision, data sampling frequency, and referential URLs. NA represents the ones that the corresponding information was not able to be found online. Readers need to follow the data policy of each institute when they wish to use data for their own purpose.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2022.105102.

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