Convolutional Neural Network Considering Physical Processes and its Application to Diatom Detection

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***Abstracts*—Convolutional Neural Network (CNN) considering physical processes with time series of stages for diatom detection with remote sensing satellite derived physical data (Chlorophyll-a, Photosynthesis Available Radiance (PAR), Turbidity, Sea Surface Temperature (SST)) and meteorological data is proposed. Diatom is bloomed under the condition of suitable sea water temperature, nutrition rich water (Chlorophyll-a derived from river water flow), photosynthesis available radiance derived from solar irradiance, transparency of the sea water for photosynthesis (turbidity), and sea water convection between bottom sea water and sea surface water. Almost all the conditions can be monitored by remote sensing satellite-based radiometers. The proposed diatom prediction based on convolutional neural network with remote sensing satellite and meteorological data is validated. Through the experiments at Ariake bay area, Kyushu, Japan with gathered time series of remote sensing data of Moderate resolution of Imaging Spectroradiometer (MODIS) derived turbidity as well as chlorophyll-a data estimated for the winter seasons (from January to March) during from 2010 to 2018 together with measured and acquired meteorological data for the same winter seasons, the proposed method is validated.**

***Keywords*—Chlorophyl-a concentration; red tide; diatom; MODIS; satellite remote sensing; neural network; meteorological data**

I. Introduction

One of the problems of DLM: Deep Learning Method (Convolutional Neural Network: NN, Recurrent Convolutional Neural Network: RCNN, etc.) is that DLM cannot consider time and spatial relations among data for input nodes. Also, another problem is that DLM is not supported physical processes nevertheless physical meaning is significantly important. The DLM method proposed here is to solve these problems. Namely, time series of physical processes are considered in the proposed DLM method.

In the previously proposed method [1], data gathering, and data analysis are featured for prediction of diatom appearance which occurs at Ariake Sea, Kyushu, Japan in winter season. The big data used in this research are Moderate resolution Imaging Spectroradiometer: MODIS derived turbidity and chlorophyll-a concentration data as well as meteorological data which are acquired for 9 years during from 2010 to 2018. As truth data of the diatom appearance are obtained from the shipment data of the number of cells of diatoms which are acquired with research vessel provided by the Saga Prefectural Institute of Ariake Fisheries Promotion: SPIAFP. DLM is used with the big data and the truth data.

The proposed method is required to predict when and where diatom will appear. Therefore, the prediction result must be displayed in a geographical representation. In this paper, it will be displayed onto MODIS [1] derived turbidity images because diatom appears in the not turbid sea areas usually (Photosynthesis becomes active). It is known that diatom appearance and blooming mechanism is as follows:

1) Diatom seeds are existing in sea water.

2) Nutrition rich water which is mainly containing in river water is increased in the low tide.

3) Sun illumination time which is required for photosynthesis is long enough in the low tide time period, and turbidity of sea water is small enough (transparent sea water).

4) Sea Surface Temperature: SST is appropriate for diatoms in the low tide time period, and chlorophyll-a concentration is high enough.

5) Relatively high wind which is required for convection of sea water blows during the low tide and the spring tide time periods.

6) Then diatoms appear in the spring tide time period (Blooming).

Although such these physical processes must be considered, CNN cannot consider the processes. Therefore, two stages of CNN are proposed here. Namely, turbidity, Photosynthetically Active Radiance: PAR[2], chlorophyll-a concentration as well as SST are monitored in a low tide time period as the first stage, then these parameters and wind direction and speed are also monitored in the following spring tide time period as the second stage.

All these data can be derived from MODIS of remote sensing satellite data except wind data. These imagery data which are acquired in a low tide time period can be input node data and diatom blooming distribution of imagery data can be output node data as truth data. These are training datasets for the first stage. These are same things for the second stage. These data which are acquired in the following spring tide time period are training data for the second stage. If these two stages of the result of rules are identical, then the rule can be used for diatom blooming detection. Thus, diatom blooming at the following spring tide time period can be predicted at the first stage of a low tide time period. The purpose of this study is to create a method for prediction of diatom detection by using

[1] https://modis.gsfc.nasa.gov/
[2] https://en.wikipedia.org/wiki/Photosynthetically_active_radiation

remote sensing data derived physical parameters based on physical process considered neural network.

Through experiments, it is found that the proposed prediction method for large diatom appearance is validated with the meteorological data and MODIS derived turbidity as well as chlorophyll-a data estimated for the winter (from January to March) in 2012 and 2015 [1]. This paper is to validate the proposed method with the acquired data in 2016-2018.

The research background and the related research works are described in the next section. Then proposed method is described in the following section followed by experiments. The experimental results are validated in the following section followed by conclusion with some discussions.

II. Research Background and Related Research

The Ariake Sea is the largest productive area of Nori (Porphyra yezoensis[3]) in Japan. In winters in 2012, 2013, 2014 and 2015, a massive diatom bloom appeared in the Ariake Bay, Japan [2]. In case of above red tides, bloom causative was Eucampia zodiacus[4]. This bloom has been occurred several coastal areas in Japan and is well reported by Nishikawa et al. for Harima-nada sea areas [3]-[11]. Diatom blooms have recurrently appeared from late autumn to early spring in the coastal waters of western Japan, such as the Ariake Bay [12] and the Seto Inland Sea [13], where large scale "Nori" aquaculture occurs. Diatom blooms have caused the exhaustion of nutrients in the water column during the "Nori" harvest season.

It is serious problem of red tide damage to Nori production. Approximately 30% of amount of Nori sales is getting down by discoloration of Nori due to red tide damage of diatom appearance. This damage can be avoided. Namely, the damage can be stopped by pulling the nori net above the sea at the time of red tide occurrence. Therefore, it is desirable to predict diatom appearance and inform some cautions to Nori fisherman.

The chlorophyll-a concentration algorithm developed for MODIS has been validated [14]. The algorithm is applied to MODIS data for a trend analysis of chlorophyll-a distribution in the Ariake Bay in winter during from 2010 to 2015 is made [14]. Also, locality of red tide appearance in Ariake Sea including Ariake Bay, Isahaya Bay and Kumamoto offshore is clarified by using MODIS data derived chlorophyll-a concentration [15].

Satellite and Ground based red tide detection method and system by means of peak shift of remote sensing reflectance is proposed [16]. Also, a method for red tide detection and discrimination of red tide type (spherical and non-spherical shapes of red tide) through polarization measurements of sea surface is proposed [17]. Red tide detection using remote sensing satellites, research vessels, and ground based red tide monitoring system and discrimination of red tide species is reported [18]. Comparative study on discrimination methods for identifying dangerous red tide species based on wavelet utilized classification methods is conducted [19]. Relation between chlorophyll-a concentration and red tide in the intensive study area of the Ariake Sea is investigated [20].

Trend analysis of relatively large diatoms which appear in the intensive study area of the Ariake Sea, Japan in winter (2011-2015) based on remote sensing satellite data is carried out [14]. Then, one of the possible causes for diatom appearance in Ariake bay area in Japan in the winter from 2010 to 2015 (Clarified with AQUA[5]/MODIS) is reported [21]. Relation between large sized diatom appearance and meteorological data in Ariake bay area in Japan in the winter in 2016 is reported [22]. Then, prediction method for large diatom appearance with meteorological data and MODIS derived turbidity and chlorophyll-a in Ariake bay area in Japan is proposed [1].

Rhizosolenia imbricata[6] as a large diatom in winter season has been suppressed by the shortage of sunshine and the like due to insufficient sunshine etc. after it is transferred from the open sea into the bay in the winter with high salinity and the conditions necessary for growth (high water temperature, high illuminance, high nutrient salt, etc. It is known that large occurrence occurs when the condition is met. In addition, small diatoms such as Skeletonema spp.[7] Proliferate, the density of Eucampia zodiacus (E. zodiacus) rapidly increases from late February after decline. In addition, E. zodiacus is widely distributed from the surface layer to the bottom layer, and the nutrient concentration decreases sharply with the growth of E. zodiacus. The cell density of E. zodiacus that was distributed in the bottom layer of the offshore region increased from the low tide to the high tide and the turbidity decreased mainly in the offshore region at the low tide period before the cell density of E. zodiacus increased. There is a tendency to do. In early March, when the cell density of E. zodiacus sharply increased, it is also known that there is a low salt water mass at the surface layer.

From Itoh et al. (2013) [2], it is considered important for the sedimented. zodiacus to improve the light environment at low tide in order to expand the population to the red tide level. In addition, from the comparison of observation results between 2007 and 2012, whether to rapidly expand the population at the high tide following E. zodiacus that was distributed in the deep layer at the time of tidal wave is related to river flow (supply of nutrient salt) It is said to be dependent. Author in [2] also described empirical mechanism of the diatom blooming. Therefore, the rules for prediction of diatom occurrence are compared to the empirically found mechanism. On the other hand, the occurrence of red tide caused by Asteroplanus karianus [8] (A. karianus) in the waters of Saga prefecture has been reported to be constantly increasing and densifying since FY 2007, and the cell density of A. karianus tends to increase after late December, A. Karianus is known to tend to be densified upstream of Shiotagawa river feeling tide area in the Ariake Sea Saga prefecture. Also, in the Ariake Sea,

[3] http://en.wikipedia.org/wiki/Porphyra
[4] http://www.eos.ubc.ca/research/phytoplankton/diatoms/centric/eucampia/e_zodiacus.html
[5] https://aqua.nasa.gov/
[6] http://www.marinespecies.org/aphia.php?p=taxdetails&id=149116
[7] http://www.marinebio.org/species.asp?id=4834
[8] http://www.godac.jamstec.go.jp/bismal/j/view/9031783

A. karianus has not reported the formation of red tide in areas other than the sea area of Saga prefecture.

Prediction method for large diatom appearance in winter with meteorological data and MODIS derived turbidity and chlorophyll-a in Ariake Bay Area in Japan is proposed. Mechanism for large diatom appearance in winter is discussed with the influencing factors, meteorological condition and in-situ data of turbidity, chlorophyll-a data with the measuring instruments equipped at the Saga University own Tower in the Ariake Bay area. Particularly, the method for estimation of turbidity is still under discussion. Therefore, the algorithm for estimation of turbidity with MODIS data is proposed.

III. Proposed Diatom Appearance Prediction

A. Big Data Anlysis

Because of remote sensing satellite imagery data and meteorological data are essentially big; a big data analysis must be done for diatom prediction (Estimation of time/location/size). Big data analysis can be done through the following procedure and typical tools.

1) Data gathering: Import.IO[9], etc.

2) Storage and management: Hadoop [10], Cloudera [11], MongoDB[12], Talend[13], etc.

3) Data cleaning: OpenRefine[14], Data cleaner[15], etc.

4) Data mining: IBM SPSS Modeler [16], Oracle Data Mining[17], Tera Data[18], Kaggle[19], etc.

5) Data analysis: Qubole [20], BigML [21], Statwing [22], Tableau[23], CartDB[24], Chartio[25], Plot.ly[26], Datawrapper[27], etc.

6) Data visualization: Tableau [28], CartDB [29], Chartio [30], Plot.ly, Datawrapper, etc.

7) Data integration: Blockspring [31], Pentaho [32], etc. and Data language of "R", "Python", "RegEx[33]", "XPath[34]", etc.

Import IO is used for gathering MODIS derived chlorophyll concentration and turbidity of the ocean areas in concern (Coastal areas of Ariake Bay which are situated in northern Kyushu, Japan). Hadoop is used for data management while OpenRefine is also used for data cleaning. On the other hand, DLM is used for learning diatom appearances. The learnt result for diatom appearance is compared to the empirical knowledge about diatom occurrences. As the results, the proposed method for diatom appearance prediction rules is reasonable in comparison to the empirical reasons.

B. Diatom Appearnce in Ariake Sea

Rhizosolenia imbricata (R. imbricate) is mainly assumed as a large diatom. In R. imbricata, the necessary conditions for growth (high water temperature, high illuminance, high nutrient salt, etc.) are established after small diatom growth is suppressed due to lack of sunshine, etc. due to lack of sunshine, etc. and a big outbreak. On the other hand, Eucampia zodiacus (E. zodiacus) has the following characteristics,

- Vertical axis length 13 to 100 μm.
- The cells are flat wedge-shaped, forming a spiral group consisting of several cells.
- Widely distributed in coastal areas around the world excluding the polar regions
- Can grow under a wide range of water temperature and salt conditions (optimal water temperature is 25° C).
- Growth requires relatively high light conditions.
- Maintains high nitrogen uptake ability even under low water temperature conditions
- The existence of dormant cells has not been confirmed.

These two major diatoms in the Ariake see in winter season. E. zodiacus is dominant recently. Therefore, it is important to predict E. zodiacus appearance.

C. Physical Proccesses for Diatom Appearance

From late February after the growth and decline of small diatoms such as Skeletonema spp., the cell density of E. zodiacus increased rapidly. E. zodiacus is widely distributed from the surface layer to the bottom layer.

As E. zodiacus grew, the nutrient concentration decreased rapidly. The cell density of E. zodiacus, which was distributed in the bottom of the offshore area, increased during the period from low tide to high tide.

The tendency of turbidity to decrease mainly in the offshore region during the tidal period before the cell density of E. zodiacus increases

In early March, when the cell density of E. zodiacus increased rapidly, there was a low-salt water mass on the surface layer.

D. Examples of Physical Proccesses for Diatom Appearance

For E. zodiacus, which is sinking, to expand its population to the red tide level, it is important to improve the light environment at low tide. From the comparison of observation

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[9] https://www.import.io/
[10] https://ja.wikipedia.org/wiki/Apache_Hadoop
[11] https://www.cloudera.com/
[12] https://www.mongodb.com/
[13] https://qiita.com/kazu56/items/b089ded9af884426f008
[14] http://openrefine.org/
[15] https://datacleaner.org/
[16] https://www.ibm.com/products/spss-modeler
[17] https://www.oracle.com/technetwork/database/options/advanced-analytics/odm/overview/index.html
[18] https://www.teradata.jp/About-Us
[19] https://www.kaggle.com/
[20] https://www.qubole.com/
[21] https://bigml.com/
[22] https://www.statwing.com/
[23] https://www.tableau.com/ja-jp
[24] https://carto.com/
[25] https://chartio.com/
[26] https://plot.ly/
[27] https://www.datawrapper.de/
[28] https://tableau-i-ways.com/about
[29] https://en.wikipedia.org/wiki/CartoDB
[30] https://www.g2crowd.com/products/chartio/reviews
[31] https://www.blockspring.com/
[32] https://www.hitachivantara.com/go/pentaho.html
[33] https://docs.microsoft.com/jajp/dotnet/api/system.text.regularex pressions.regex?view=netframework-4.7.2
[34] https://ja.wikipedia.org/wiki/XML_Path_Language

results in 2007 and 2012, whether the population expands suddenly at the time of the storm followed by E. zodiacus distributed in the deep layer at the time of the low tide depends on the river flow (nutrient supply). Fig. 1 shows the diatom appearance mechanism and the examples of the mechanism for 2007 and 2012.

In 2012, precipitation on February 8, chlorophyll a and PAR increase after February 10, DIN (Dissolved Inorganic Nitrogen), PO_4-P (Phosphorus phosphate), SiO_2-Si (silicate silicon) increase on February 18, and temperature rises results in Skeletonema increases on February 24 Occurrence. Chlorophyll a and PAR increased after February 10, and DIN, PO_4-P, and SiO_2-Si increased until February 18, but the temperature dropped sharply from February 16 and the wind speed increased rapidly.

DIN, PO_4 -P, plummeted, then Skeletonema plummeted on February 24. There was precipitation on February 24, then PAR increased rapidly, the temperature rose on February 20-25, the surface SiO_2-Si continued, and then a large amount of Eucampia occurred. Since February 24, temperatures have fallen and chlorophyll a has decreased, but Eucampia, which does not require nutrients, has continued to occur.

Therefore, it would be better to consider the two stages in the learning process with DLM, namely, the first stage of "Low Tide" and the second stage of "Spring Tide" The input data of the first stage are Chlorophyll-a, turbidity, photosynthetically active radiance derived from MODIS data. Also, the desired output is true: diatom blooming or false: no diatom blooming. Meanwhile, the input data and the desired output of the second stage are same as the first stage. After the learning processes of the first and the second stages, the results must be associated as follows,

1) Diatom Blooming: True for the first and second stages.
2) No Diatom Blooming: the other cases.

The desired output can be obtained from the SPIAFP. SPIAFP provides the number of cells a ml in the Ariake sea areas by species by species and by the district by district (see Fig. 3(a)). Thus, physical mechanism and time sequence are considered in the proposed learning process.

River water can be monitored together with sunshine time a day. Also, wind direction and wind speed are monitored by meteorological agency. SST, chlorophyll-a concentration and Suspended Solid: SS can be monitored with satellite remote sensing data in a daily basis. Therefore, diatom appearance can be predicted. For SST, chlorophyll-a concentration and SS are represented as images. Therefore, machine learning can be done for prediction of SST, chlorophyll-a concentration and SS as well as diatom appearance.

Therefore, it is possible to predict diatom appearance with the time series of parameters. The proposed big data analysis-based method is based on the well-known machine learning with the time series of rainfall volume, river water volume, air temperature, tide level, wind direction / wind speed, solar radiation, turbidity sea surface temperature, and chlorophyll-a derived from time series of remote sensing satellite data. The machine learning process can learn the most appropriate prediction method. Using 9 years of these data (2010 to 2018), the machine learning is done and finds the most appropriate way and conditions are found.

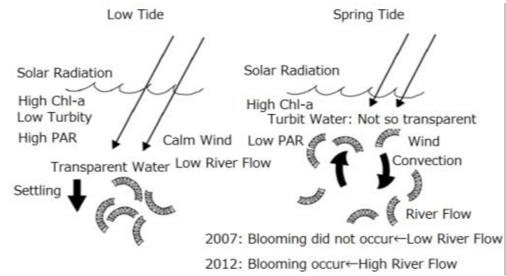


Fig. 1. Examples of Diatom Appearance Mechanism in 2007 and 2012.

For the input node, there are tidal data, sea surface temperature, river flow rate, wind direction and wind speed, turbidity and chlorophyll-a concentration derived from MODIS data. From the 9 years ground truth data of diatom appearance data are also inputted as desired outputs as training datasets. Thus, the proposed DLM can lean for diatom appearance detection.

IV. Experiments for Validation

A. Intensive Study Area

Intensive study areas of Ariake Sea, Isahaya Bay, and Kumamoto Offshore are shown in Fig. 2. Ariake Bay is a portion of Ariake Sea of which the width is around 20 km (in direction of east to west) and the length is approximately 100 km (in direction of north to south). It is almost closed sea area because the mouth of Ariake Sea is quite narrow. Sea water exchanges are, therefore, very small.

B. Truth Data and MODIS Derived Turbidity and Chlorophyll-a Concentration Data of Diatom Appearance

Truth data of diatom distribution which are measure with research vessels and MODIS data derived turbidity, chlorophyll-a concentration and PAR data in unit of Einstein unit of E/m^2/day as well as the time series of bi-monthly PAR data in the case of diatom appearance are shown in Fig. 3(a), (b), (c), (d) and (e), respectively. Also, Tables I and II show the measured diatom distribution together with the number of cells and diatom species, respectively.

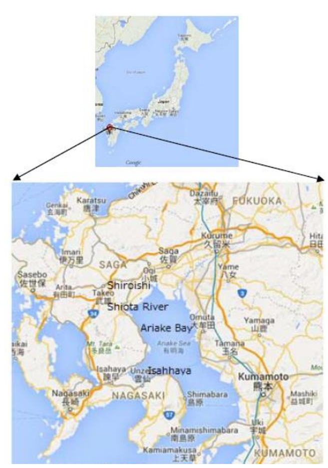
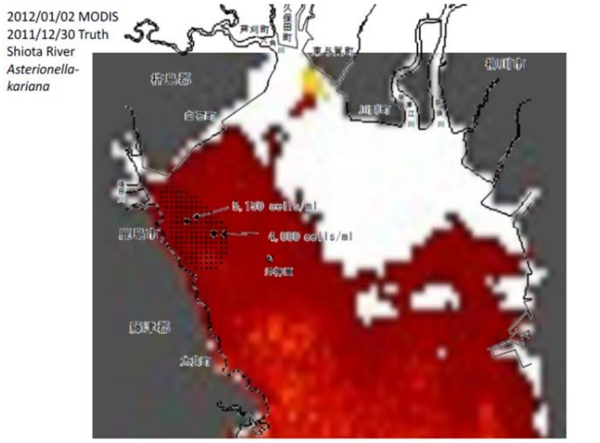
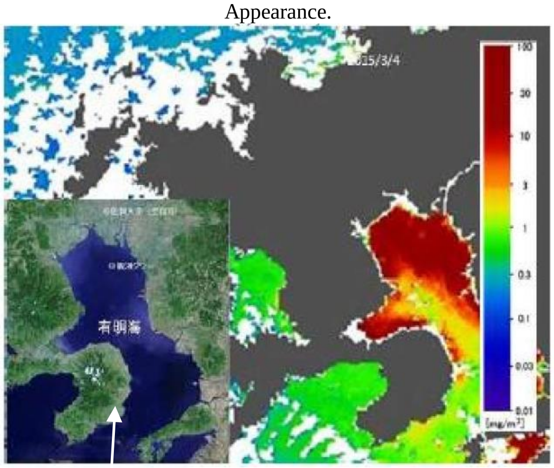


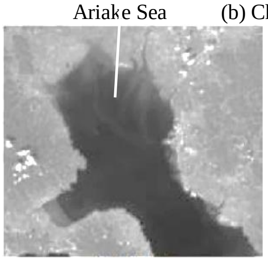
Fig. 2. Intensive Study Areas.



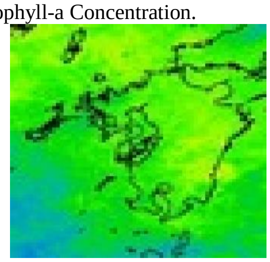
(a) Example of MODIS Derived Chlorophyll-a Concentration and Diatom Appearance.



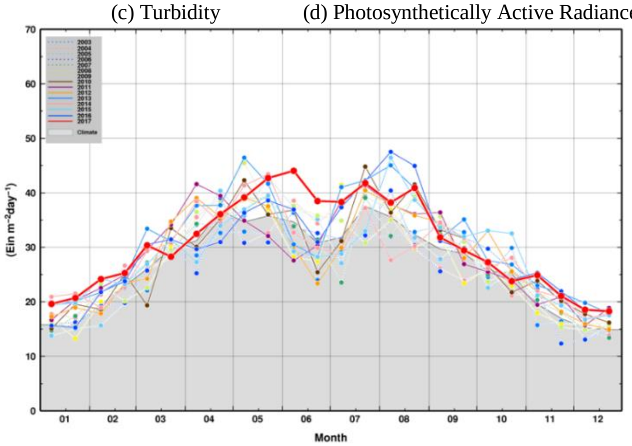
Ariake Sea (b) Chlorophyll-a Concentration.



(c) Turbidity



(d) Photosynthetically Active Radiance.



(e) Time Series Data of the Bimonthly PAR.

Fig. 3. Truth Data of Diatom Distribution which are Measured with Research Vessels and MODIS Data Derived Turbidity, Chlorophyll-a Concentration and PAR Data as well as the Time Series of bi-Monthly PAR Data in the Case of Diatom Appearance.

TABLE I. MAJOR SPECIES AND THE NUMBER OF RED TIDE INCLUDING DIATOMS APPEARED IN ARIAKE BAY AREA IN THE TIME PERIOD FROM JANUARY TO FEBRUARY IN 2010 TO 2018

January 21, 2010 Shiota river mouth and its surrounding areas Asteroplanus karianus; 3280 cells/ml Skeletonema costatum: 1330 cells/ml
January11 2011 Along with the Shiroishi town offshore to the Shiota river mouth and its surrounding areas, Asteroplanus karianus; 10150 cells/ml
February 25, 2011 Around the Kashima offshore Asteroplanus karianus; 4950 cells/ml
December 30, 2011 Around the Shiota River Mouth and its surrounding areas Asteroplanus karianus; 5150 cells/ml
January 23, 2012 around Shiota river mouth and its surrounding areas as well as Shiroishi offshore Skeletonema spp .: 5150 cells/ml
February 22, 2012 Along with the Kawazoe offshore to the Tara offshore Eucampia zodiacus: 1,090 cells/ml
December 31, 2012 Along with the Shiota river mouth and its surrounding areas to the Kashima offshore Skeletonema spp.: 6110 cells/ml
January 7, 2013 Along with the Shiota river mouth and its surrounding areas to the Shiroishi offshore Asteroplanus karianus 5630 cells/ml Skeletonema costatum: 3390 cells/ml
January 6, 2014 Shiroishi offshore Asteroplanus karianus; 4830 cells/ml
January 16, 2014 Shiroishi offshore Skeletonema spp.: 6110 cells/ml Thalassiosira spp.: 1510 cells/ml
February 6, 2014 Almost whole Ariake bay area except the Shiroishi offshore Eucampia zodiacus: 568 cells/ml
December 30, 2014 Along with the Shiroishi offshore to the Tara offshore Asteroplanus karianus; 3890 cells/ml Skeletonema costatum: 8750 cells/ml
March 6, 2015 Along with the Kashima offshore to the Tara offshore Eucampia zodiacus: 1310 cells/ml
March 24, 2016 Shiroishi offshore Skeletonem spp. of 12,880 cells/ml
December 29, 2016: Skeletonema, Asteroplanus karianus February 20, 2017 Skeletonema, Asteroplanus karianus , Kirosloth, Eucampier March 6, 2017: Skeletonema, Asteroplanus karianus March 13, 2017: Skeletonema, Asteroplanus karianus, Eucampia March 21, 2017: Skeletonema, Asteroplanus karianus
November 1, 2017: Skeetonema, Keatheros November 5, 2017: Skeetonema, Keatheros November 12, 2017: Skeetonema, Keatheros November 20, 2017: Skeletonema, Keatheros, Lisosolenia November 27, 2017: Skeletonema, Keatheros, Lisosolenia December 4, 2017: Skeetonema, Keatheros, Lisosolenia December 13, 2017: Skeletonema, Keatheros, Lisosolenia, Asteroplanus karianus, Eucampia December 28, 2017: Skeletonema, Keatheros, Lisosolenia, Asteroplanus karianus

TABLE. II. DAYS FOR MODIS DATA ARE ACQUIRED

(2010) January 1, 3, 9, 14, 16, 17, 18, 22, 24, 26, 27, 29, February 3, 4, 5, 6, 20, 21, 23, and 28 in 2010
(2011) January 1, 2, 7, 8, 14, 17, 22, 26, 27, February 1, 3, 4, 15, 21, 22, 24, and 26 in 2011
(2012) January 2, 6, 7, 12, 17, 20, 21, 23, 26, 29, 30, 31, February 4, 11, 12, 20, 24, and 29 in 2012
(2013) January 4, 6, 10, 11, 12, 15, 18, 25, 28, 30, 31, February 2, 3, 10, 13, 16, 20, 22, 23, 24, and 29 in 2013
(2014) January 10, 13, 15, 16, 19, 23, 24, 26, 27, 29, 30, February 4, 8, 11, 12, 20, 21, 23, and 24 in 2014
(2015) January 4, 6, 7, 8, 9, 10, 12, 17, 18, 20, 23, February 1, 3, 6, 9, 13, 14, 20, and 27 in 2015
(2016) January 7, 10, 16, 22, 30, February 3, 4, 9, 10, 18, 21, 24, 26 and March 1 in 2016
(2017) January 1, 3, 4, 6, 11, 14, 16, 17, 21, 25, 26, 28, 30, February 1, 2, 3, 6, 13, 15, 18, 19, 21, 28, March 2, 3, 5, 6, 9, 11, 14, 15, 16, 20, 21, 23, 27, 28
(2018) January 1, 2, 3, 6

One of the examples of MODIS derived chlorophyll-a concentration distribution and the truth data of diatom appearance which is occurred in 2012 is shown in Fig. 3(a). In the image, both images are superimposed. White portions of MODIS image are the cloud covered areas. The numbers in the truth data of image show the number of diatom cells per ml. Both images show a good coincide. Namely, the diatom appears at the areas of which chlorophyll-a is densely concentrated. This is a just one example. Other than this MODIS derived chlorophyll-a data, MODIS derived turbidity, SST, meteorological data of rainfall volume, river water volume, air temperature, tide level, wind direction/speed, solar radiation, are gathered.

C. *Validation of the Proposed Method forWinter Diatom (2011-2012) Diatom Appearance Prediction Method*

From the published paper, it is proposed the rule-based diatom appearance prediction method [1]. The previous paper indicates that the diatom appearance prediction can be done with rainfall volume, river water volume, air temperature, tide level, wind direction / wind speed, solar radiation, turbidity (which is corresponding to Suspended Solid: SS), sea surface temperature, and chlorophyll-a concentration derived from time series of remote sensing satellite data. One of the examples is shown in Fig. 4.

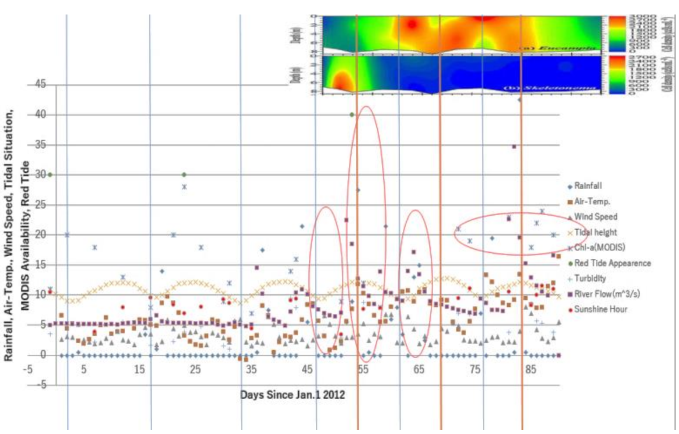


Fig. 4. Example of Diatom Appearance with the Conditions of Time Series of Data are Matched to the Threshold of the Appearance.

Relatively small size diatoms appear at western side of Ariake bay area in the middle of February and then large size diatoms appear in the whole area of Ariake bay area from 25 February to the middle of April 2012. The influencing factors, meteorological condition, turbidity, chlorophyll-a, river water flow, tidal height is collected from the Japanese Meteorological Agency: JMA, MODIS data and diatom appearance. These data of 2012 are plotted in Fig. 4. In the figure, Eucampia zodiacus (top) and Skeletonema spp. (bottom) appearances which are reported by the Ito et al. [1]. As a matter of fact, diatom needs nutrients, sunshine, appropriate sea temperature (22 to 26 degree Celsius) and salinity (15 to 28 ‰), as well as diatom seeds. Nutrients are provided by river water (source of nutrients) which is mainly caused by rainfall and run-off water. Therefore, river water flow is a key component for nutrients. Relatively large diatom (Eucampia zodiacus) seeds are situated in the bottom layer situated in Ariake bay while relatively small diatom seeds are situated from the sensory ranges of the specific rivers, Shiota- River for Skeletonema spp. and Asteroplanus karianus. Therefore, convection or vertical mixing in the sea water of Ariake bay is a key for the large diatom appearance at the sea surface.

The convection is usually occurred due to spring tide or strong winds from the north. Therefore, diatom bloom is used to be occurred in spring tide. Also, diatom seeds need sunshine, nutrients for blooming. Therefore, diatom bloom occurs after a relatively large river water flow followed by relatively small turbidity and sunshine as well as spring tide. These are mechanism for diatom appearance and blooming.

D. *Validation of the Winter Diatom (2017 – 2018) Diatom Appearance Prediction Method*

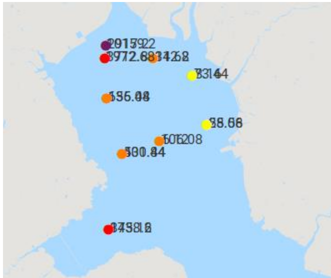
Furthermore, the diatom red tide occurrence situation from November 2017 to the present is as follows:

November/1: Skeetonema, Keatheros
November/5: Skeetonema, Keatheros
November/12: Skeetonema, Keatheros
November/20: Skeletonema, Keatheros, Lisosolenia
November/27: Skeletonema, Keatheros, Lisosolenia
December/4: Skeetonema, Keatheros, Lisosolenia
December/13: Skeletonema, Keatheros, Lisosolenia, Asteriopranos, Eucampia
December/28: Skeletonema, Keatheros, Lisosolenia, Asteriopranos

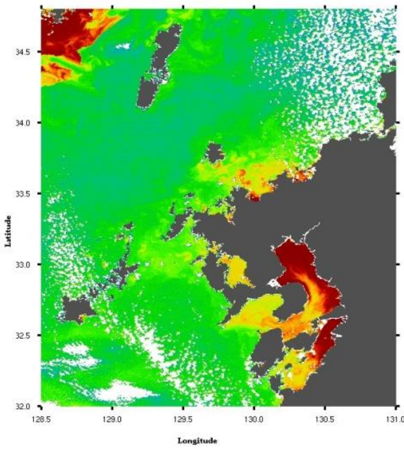
These diatom red tide spatial distributions are known. For instance, Skeletonema distribution, chlorophyll-a concentration and 10 days average of the sea surface temperature of January 4, 2018 is shown in Fig. 5(a), (b), and (c), respectively.

The diatom red tide space distribution is also known. In addition, sunshine hours, tide levels and river flow rates during this period are shown in Fig. 6, 7 and 8, respectively. In addition, Fig. 9 shows the wind speed northward from November 1, 2017 to January 31, 2018.

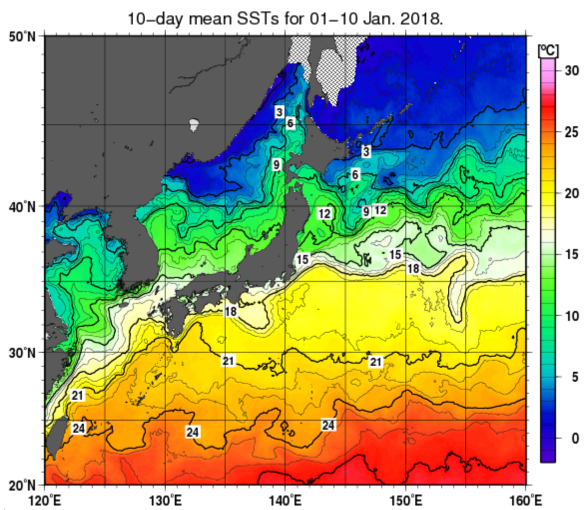
In these figures, blue colored down arrow denotes diatom occurrences. In particular, the last three arrow shows large diatom appearances. These figures show that the large diatom appearances are occurred in the spring tide time periods, relatively large river flow are observed in the November 2017, there are comparatively long sunshine hours in low tide time periods, and there are relatively strong winds from the north direction during the time periods from low tide and spring tide.



a) Skeletonema Distribution (the Numbers in the Figure shows the Number of Cells Per ml)



(b) Chlorophyll-a Concentration.



(c) Sea Surface Temperature of January 4, 2018.

Fig. 5. Skeletonema Distribution, Chlorophyll-a Concentration, and 10 Days Average of the Sea Surface Temperature of January 4, 2018.

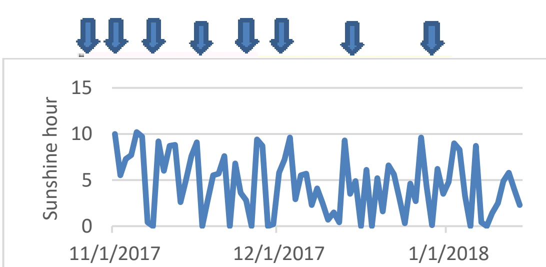


Fig. 6. Sunshine Hours from November 1, 2017 to January 31, 2018.

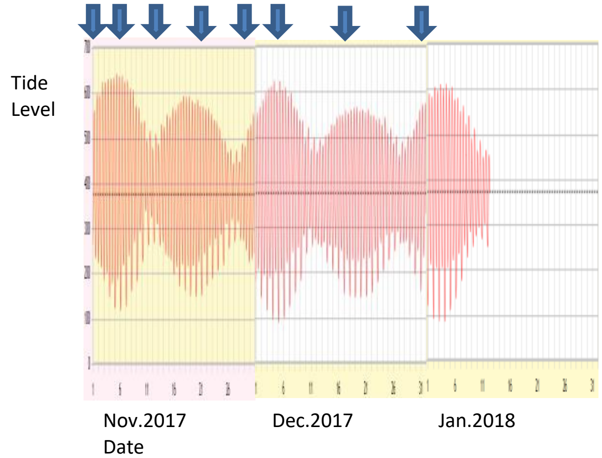


Fig. 7. Tide Level from 1 November 2017 to 31 March 2018.

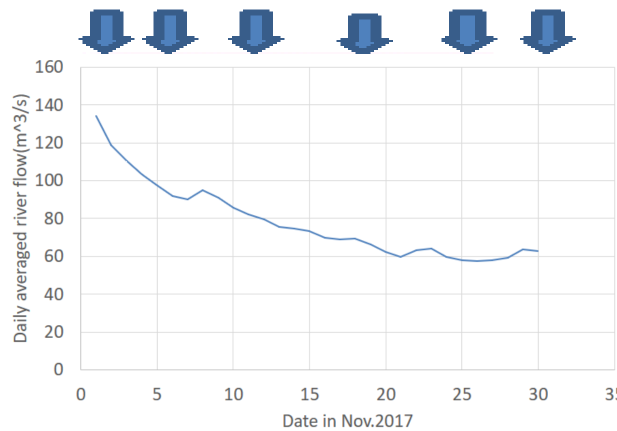


Fig. 8. River Flow Rate from November 1, 2017 to November 30, 2017.

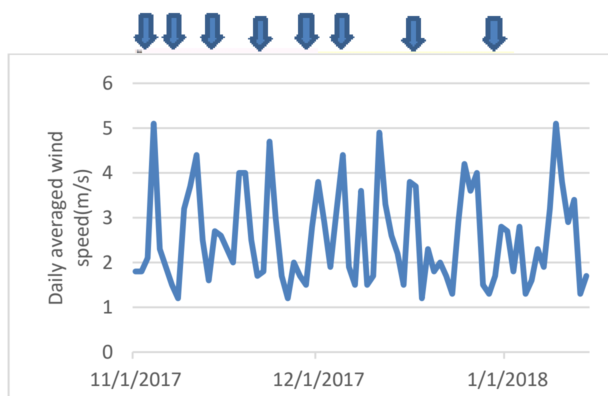


Fig. 9. Northernmost Wind Speed from November 1, 2017 to January 31, 2018.

Therefore, the proposed diatom detection method derived from the 9 years data of MODIS derived chlorophyll-a concentration data together with turbidity data as well as meteorological data is validated with the 2017 to 2018 data of these data.

The sea surface temperature declined after the middle of January 2017, but until then it has kept over 15 degrees and the condition of relatively high sea surface temperature continued.

Occurrence of Eucampia after February 20 is the high tide period, the wind to the north is stronger just before that, the turbidity is low in the low tide period before that, the solar radiation is large, and the river flow rate was large just before that.

From November 2017, although the amount is small, Skeetonema, Frequent Ketotheros, after 20 days Lysosrenia has occurred. Sea surface temperature declines from mid-December 2017, the sea surface temperature is lower than 2016. Increase of chlorophyll concentration after January 2018.

V. Conclusion

CNN considering physical processes with time series of stages for diatom detection with remote sensing satellite derived physical data and meteorological data is proposed. Previously proposed diatom prediction based on neural network with remote sensing satellite and meteorological data is validated. Through the experiments at Ariake bay area, Kyushu, Japan with gathered time series of remote sensing data of MODIS derived turbidity as well as chlorophyll-a data estimated for the winter seasons (from January to March) during from 2010 to 2018 together with measured and acquired meteorological data for the same winter seasons, the proposed method is validated.

Diatom appearance prediction method with big data of remote sensing satellite data and meteorological data is proposed together with validation of the proposed method. Through the experiments at Ariake bay area, Kyushu, Japan with gathered time series of remote sensing data of MODIS derived turbidity as well as chlorophyll-a data estimated for the winter (from January to March) during from 2010 to 2018 together with measured and acquired meteorological data for the same winter seasons, the proposed method is validated.

The sea surface temperature declined after the middle of January 2017, but it kept at least 15 °C until then, and the condition of relatively high sea surface temperature continued. Occurrence of Eucampia after February 20 is the high tide period, the wind to the north is stronger just before that, the turbidity is low in the low tide period before that, the solar radiation is large, and the river flow rate was large just before that. Also, since November 2017, although the amount is small, Skeletonema, Frequent Ketotheros occurred, Lisosolenia occurred after 20 days, the temperature of the sea surface declined since mid-December 2017, the sea surface temperature is lower than the year 2016. Chlorophyll concentration has been rising since January 2018. More importantly, it is found that the empirically found mechanism of diatom appearance shows coincide to the rules of diatom blooming predicted by the proposed method.

Further investigations are required for establishment of a method for predicting the seasonal surface environment Nowcasting to winter diatom red tide detection. Also, further study is required to check the possibility of using Japan Aeronautics Exploration Agency: JAXA satellite-borne SGLI[35] and Setinel-2, 3 / MSI[36] and try to use COMS / GOCI[37]. Applied to collaborative research with JAXA on research plan on winter diatom red tide prediction by SGLI, calibration of SGLI by Saga University observation tower data, etc. estimation of sea surface emission luminance, chlorophyll a, turbidity, etc. Estimation method will be studied.

[35] https://suzaku.eorc.jaxa.jp/GCOM_C/index_j.html
[36] https://sentinel.esa.int/web/sentinel/technical-guides/sentinel-2-msi
[37] https://oceancolor.gsfc.nasa.gov/data/goci/

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