

Preliminary Study on Phytoplankton Distribution Changes Monitoring for the Intensive Study Area of the Ariake Sea, Japan Based on Remote Sensing Satellite Data

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Abstract—Phytoplankton distribution changes in the Ariake Sea areas, Japan based on remote sensing satellite data is studied. Through experiments with Terra and AQUA MODIS data derived chlorophyll-a concentration and suspended solid as well as truth data of chlorophyll-a concentration together with meteorological data and tidal data which are acquired 7 months from October 2012 to April 2013, it is found that strong correlation between the truth data of chlorophyll-a and MODIS derived chlorophyll-a concentrations with R square value ranges from 0.677 to 0.791. Also it is found that the relations between ocean wind speed and chlorophyll-a concentration as well as between tidal effects and chlorophyll-a concentration. Meanwhile, there is a relatively high correlation between sunshine duration a day and chlorophyll-a concentration.

Keywords—chlorophyll-a concentration; suspended solid; ocean winds.

I. INTRODUCTION

Due to red tide contaminations, water color is changed by an algal bloom. In accordance with increasing of phytoplankton concentration, sea surface color changes from blue to green as well as to red or brown depending on the majority of phytoplankton (Dierrsen et al, 2006) so that it is capable to detect red tide using this color changes [1].

MODIS ocean color bands data is used for red tide detection. An iterative approach (Arnone et al., 1998 [2]; Stumpf et al., 2003 [3]) for sediment-rich waters, based on the Gordon and Wang (1994) algorithm [4], is used to correct for the atmospheric interference in the six ocean color bands in turbid coastal waters to obtain water leaving radiance, which are then used in the band-ratio algorithm (O'Reilly et al., 2000 [5]) to estimate Chlorophyll in unit of mg m^{-3} . Also suspended solid is estimated with two bands algorithm (visible minus near infrared bands data). The multi-channels of red tide detection algorithms (in the formula of $C=(R_i-R_j)/(R_k-R_l)$ where R_i , R_j , R_k and R_l are the reflectivity derived from bands i , j , k and l .) are proposed. Also learning approaches based on k-nearest neighbors, random forests and support vector machines have been proposed for red tide detection with Moderate Resolution Imaging Spectro-radiometer: MODIS satellite images (Weijian C., et al., 2009) [6].

Satellite based red tide detection does work under a fine weather condition but not under cloudy and rainy conditions obviously. Furthermore, revisit period of fine resolution of radiometer onboard satellite orbits are longer than typical red tide propagations so that it is not enough observation frequency if only remote sensing satellite is used for red tide detections. Therefore satellite-and ground-based red tide monitoring system is proposed [7]. In the ground based red tide monitoring system, green colored filtered camera and polarization camera are featured for detection of red tide and discrimination of red tide types [8].

The Ariake Sea is the largest productive area of Nori (*Porphyra yezoensis*) in Japan. In winters of 2012 and 2013, a massive diatom bloom occurred in the Ariake Sea, Japan (Ito et al. 2013). In case of above red tides, bloom causative was *Eucampia zodiacus*. This bloom had been firstly developed at the eastern part of the Ariake Sea. However, as the field observation is time-consuming, information on the developing process of the red tide, and horizontal distribution of the red tide has not yet been clarified in detail. To clarify the horizontal distribution of red tide, and its temporal change, remote sensing using satellite data is quite useful.

In this paper, the chlorophyll-a concentration algorithm developed for MODIS is firstly validated. Then apply the algorithm to MODIS data which are acquired at the Ariake Sea areas, Japan specifically. Also the relations between tidal effects and chlorophyll-a concentration as well as between ocean wind speed and chlorophyll-a concentration together with between sunshine duration a day and chlorophyll-a concentration.

In the next section, the method and procedure of the experimental study is described followed by experimental data and estimated results. Then conclusion is described with some discussions.

II. METHOD AND PROCEDURE

A. The Procedure

The procedure of the experimental study is as follows,

1) Gather the truth data of chlorophyll-a concentration measured at the observation towers in the Ariake Sea areas together with the corresponding areas of MODIS derived chlorophyll-a concentration,

2) Gather the meteorological data which includes sunshine duration a day, ocean wind speed and direction, tidal heights,

3) Correlation analysis between the truth data and MODIS derived chlorophyll-a concentration as well as between geophysical parameters, ocean wind speed, sunshine duration a day, tidal heights and chlorophyll-a concentration is made.

B. MODIS

MODIS stands for The Moderate Resolution Imaging Spectro-radiometer which allows observations of the earth's surface with a variety of wavelength regions ranges from visible to thermal infrared with spatial resolution of 250, 500 and 1000 meters. Major specifications of MODIS are shown in Table 1 and 2.

MODIS is carried on Terra and AQUA satellites with local mean time of 10:30 a.m. and 1:30 p.m. with 2330km of swath width. Therefore, it may cover entire globe within a day. MODIS data is applicable to land surface, ocean surface, and atmosphere observations as is shown in Table 2. In particular for ocean surface observations, bands 8 to 16 data are useful.

TABLE I. MAJOR SPECIFICATIONS OF MODIS¹

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	228.7 kg
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years

TABLE II. APPLICATION OF MODIS SENSOR DATA²

Primary Use	Band	Bandwidth ¹	Spectral Radiance ²	Required SNR ³
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols	3	459 - 479	35.3	243

¹ <http://modis.gsfc.nasa.gov/about/specifications.php>
² <http://modis.gsfc.nasa.gov/about/specifications.php>

Properties	Band	Bandwidth	Spectral Radiance	Required NE[delta]T(K) ⁴
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

Primary Use	Band	Bandwidth ¹	Spectral Radiance ²	Required NE[delta]T(K) ⁴
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

¹ Bands 1 to 19 are in nm; Bands 20 to 36 are in µm
² Spectral Radiance values are (W/m² -µm-sr)
³ SNR = Signal-to-noise ratio
⁴ NE(delta)T = Noise-equivalent temperature difference

Note: Performance goal is 30-40% better than required

There are following many ocean related products³,

- Angstrom Exponent
- Aerosol Optical Thickness

³ <http://oceancolor.gsfc.nasa.gov/>

- Chlorophyll a
- Downwelling diffuse attenuation coefficient at 490 nm
- Level 2 Flags
- Photosynthetically Available Radiation
- Particulate Inorganic Carbon
- Particulate Organic Carbon
- Sea Surface Temperature Quality
- Sea Surface Temperature Quality - 4um
- Remote Sensing Reflectance
- Sea Surface Temperature
- Sea Surface Temperature 4um

In this study, chlorophyll-a product is used for the experiments.

C. The Intensive Study Areas

Figure 1 shows the intensive study areas in the Ariake Sea area, Kyushu, Japan.

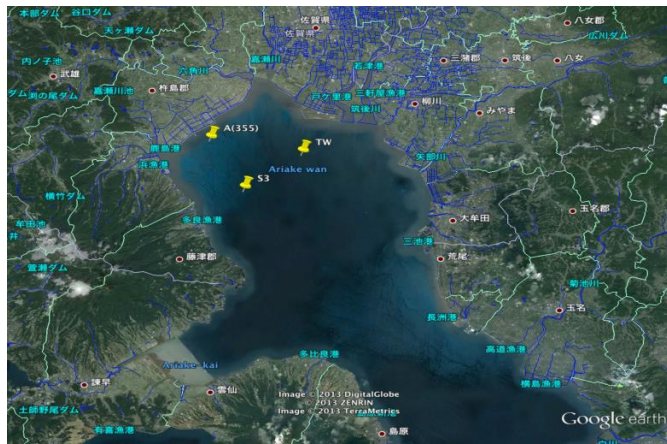


Fig 1. The Intensive study areas (Yellow pins shows the areas)

There are three observation tower points, TW, S, and A. TW is closely situated to the Saga Ariake Airport and is situated near the river mouth. On the other hand, A is situated most closely to the coastal area while S is situated in the middle point of the Ariake Sea width and is situated most far from the coastal areas and river mouths.

III. EXPERIMENTS

A. The Data Used

The truth data of chlorophyll-a concentration measured at the observation towers in the intensive study areas in the Ariake Sea areas together with the corresponding areas of MODIS derived chlorophyll-a concentration which area acquired for the observation period of 7 months during from October 2012 to April 2013 are used for the experiments. Also, the meteorological data which includes sunshine duration, ocean wind speed and direction, tidal heights which are acquired for the 7 months are used for the experiments.

Figure 2 shows an example of the chlorophyll-a concentration image which is derived from MODIS data which is acquired on 25 February 2013.

The chlorophyll-a concentration measured at the tower, TW ranges from 52 to 64 ug/l (the highest value in the 7 months). This is red tide (Phytoplankton) blooming period. Such this MODIS derived chlorophyll-a concentration data are available almost every day except cloudy and rainy conditions.

Blooming is used to be occurred when the seawater becomes nutrient rich water, calm ocean winds, long sunshine duration after convection of seawater (vertical seawater current from the bottom to sea surface). Therefore, there must exists relations between the geophysical parameters, ocean wind speed, sunshine duration, tidal heights and chlorophyll-a concentration.

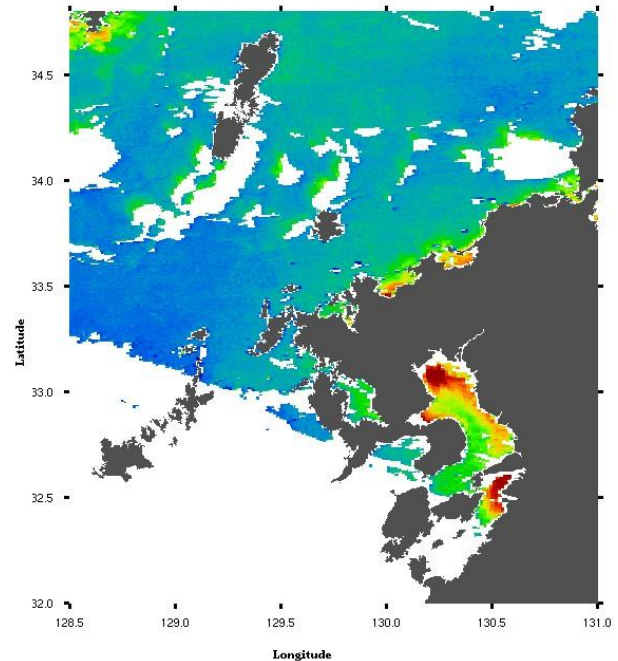


Fig 2. An example of the chlorophyll-a concentration image which is derived from MODIS data which is acquired on 25 February 2013

B. The Relation Between Truth Data and MODIS Derived Chlorophyll-a Concentrations

In order to check validity of the chlorophyll-a concentration estimation algorithm, the relation between truth and MODIS derived chlorophyll-a concentration is investigated. Figure 3 shows the relation between these for intensive study area of S while Figure 4 shows the relation for intensive study area of TW.

In the figures, L and H denote Low and High chlorophyll-a concentration of the day. Also Ch-a denotes chlorophyll-a concentration in unit of $\mu\text{g/l}$. Linear (L) denotes linear regression line for minimum chlorophyll-a concentration of the day while Linear (H) denotes that for maximum chlorophyll-a concentration of the day.

C. Trend Analysis

MODIS derived chlorophyll-a concentration which are acquired from January 4 2013 to February 28 2013 are shown in Figure 5.

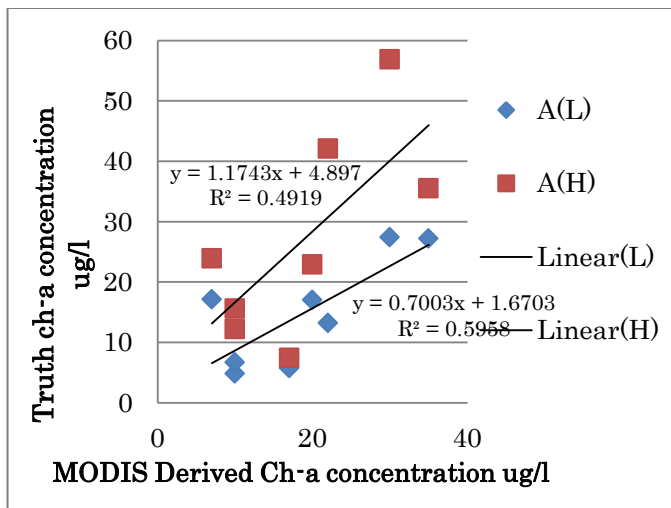


Fig 3. Relation between truth and MODIS derived chlorophyll-a concentrations for the intensive study area of S

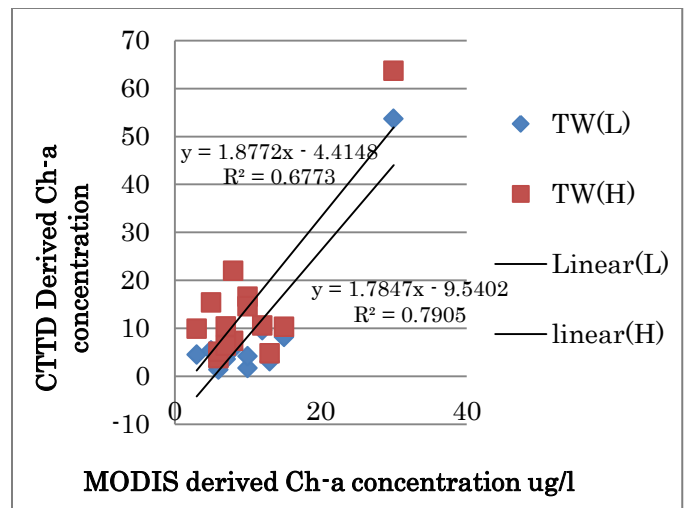


Fig 4. Relation between truth and MODIS derived chlorophyll-a concentrations for the intensive study area of TW

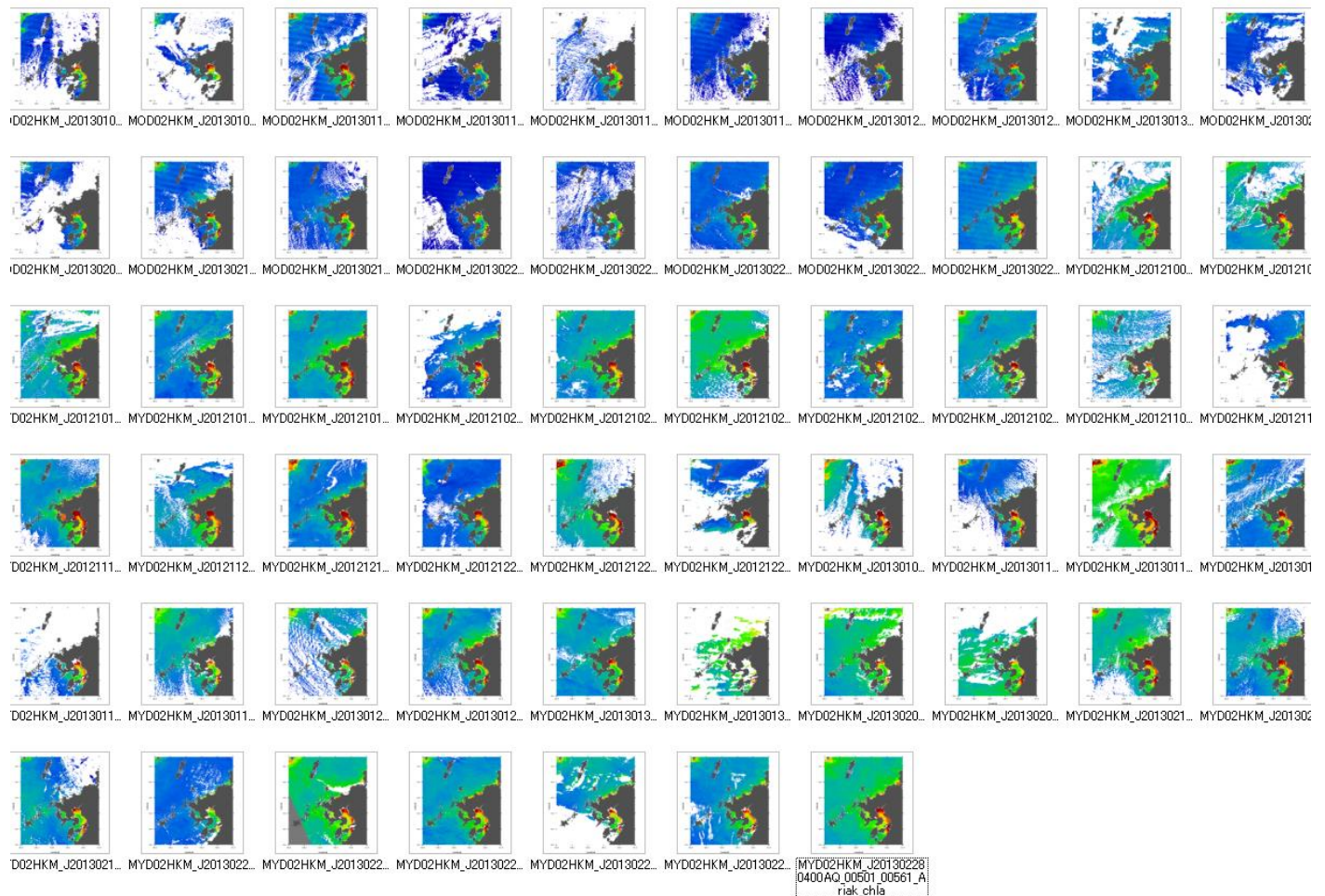


Fig 5. MODIS derived chlorophyll-a concentration in the intensive study areas which are acquired from January 4 2013 to February 28 2013

A massive red tide by large diatom of *Eucampia zodiacus* occurred from February to April, 2013 in the innermost are of the Ariake Sea. The bloom developing process are clearly detected in Figure 5.

In the first half of the Figure 5, surface chlorophyll-a concentration was low in the sea; however, it obviously increased in the middle of the Figure 5.

Finally, in the later half of the figure, quite high concentrations of chlorophyll-a were detected in the innermost area of the sea, as the Eucampia population developed. To clarify the developing mechanism of this red tide, other environmental variables such as temperature, salinity, nutrient concentrations should be further investigated.

D. Relations between geophysical parameters and chlorophyll-a concentrations

Nutrient rich seawater near the bottom is used to be flown from the sea bottom to the sea surface when the seawater convection is occurred due to ocean wind, and tidal effect. Then chlorophyll-a concentration increases in accordance with sunshine duration with the nutrient rich sea surface water. Therefore, there must exist some relations between the geophysical parameter of ocean wind, tidal effect and sunshine duration.

Figure 6 shows a relatively high relation between accumulated sunshine duration for the past three days and chlorophyll-a concentration. Ocean wind is not so strong, while tidal effect is also not so high. Therefore the relation between accumulated sun appearances time duration is proportional to the truth data of chlorophyll-a concentration.

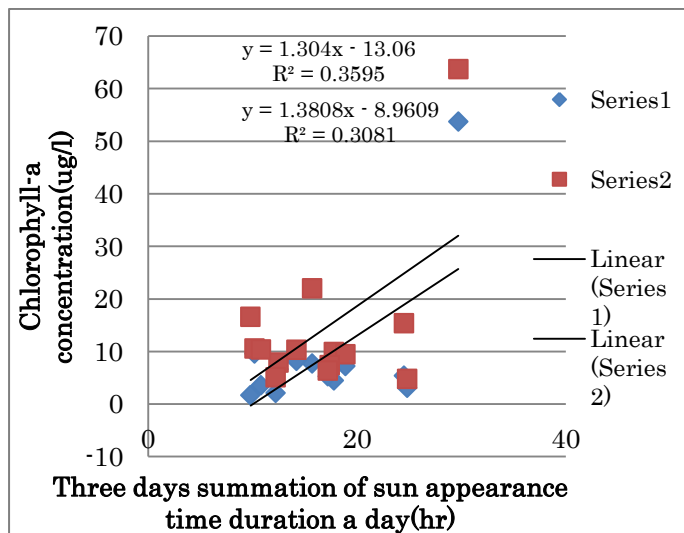


Fig 6. Relation between accumulated sunshine duration a day for the past three days and chlorophyll-a concentration

It can also be said that there are very weak relation between chlorophyll-a concentration and ocean wind as well as sea level difference a day due to the fact that ocean wind is not so high while tidal effect is not so large. Figure 7 shows the relation between chlorophyll-a concentration and accumulated daily averaged ocean wind speed for the past two days.

Meanwhile, Figure 8 shows the relation between chlorophyll-a concentration and sea surface level difference a day while Figure 9 shows the relation between chlorophyll-a concentration and the accumulated sea surface level difference for the past two days.

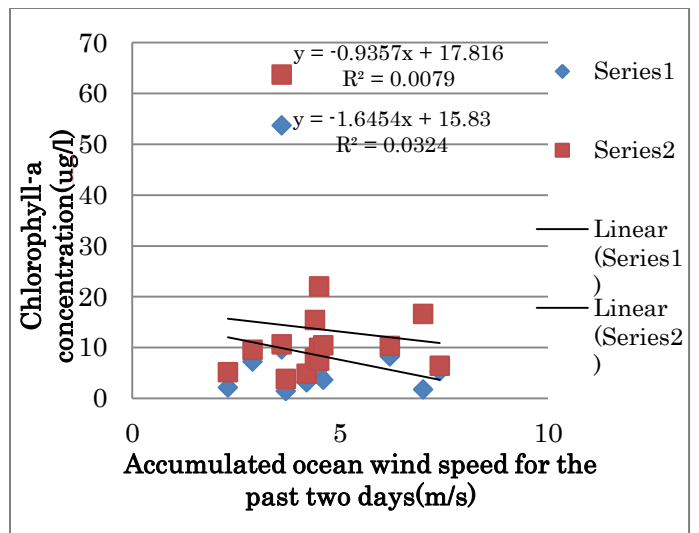


Fig 7. Relation between chlorophyll-a concentration and accumulated daily averaged ocean wind speed for the past two days.

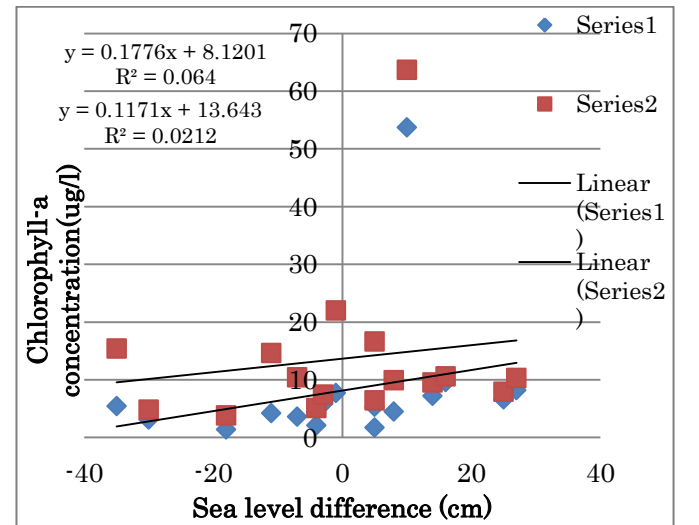


Fig 8. Relation between chlorophyll-a concentration and sea surface level difference a day

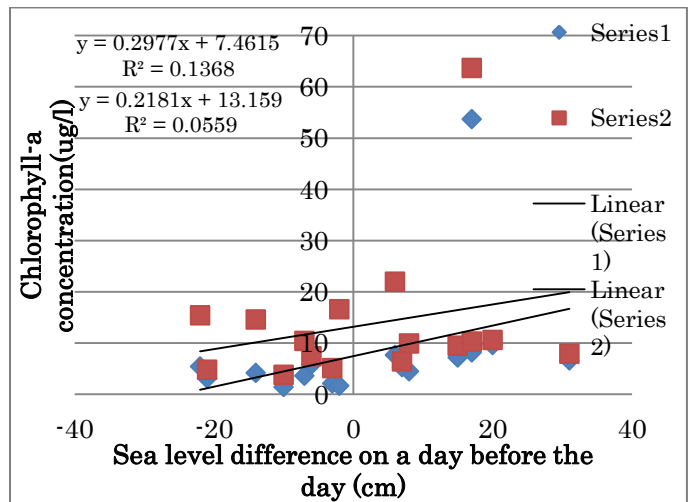


Fig 9. Relation between chlorophyll-a concentration and the accumulated sea surface level difference for the past two days.

It is confirmed that relation between ocean wind speed and chlorophyll-a concentration is weak. Also, it is confirmed that relation between sea surface level difference a day and chlorophyll-a concentration is weak. It may said that relation between two days accumulated sea surface level difference a day and chlorophyll-a concentration is higher than that between one day sea surface level difference and chlorophyll-a concentration. That is because of the fact that there is time delay of chlorophyll-a increasing after the nutrient rich bottom seawater is flown to the sea surface.

IV. CONCLUSION

Preliminary study on phytoplankton distribution changes monitoring for the intensive study area of the Ariake Sea, Japan based on remote sensing satellite data is conducted. Phytoplankton distribution changes in the Ariake Sea areas, Japan based on remote sensing satellite data is studied.

Through experiments with Terra and AQUA MODIS data derived chlorophyll-a concentration and suspended solid as well as truth data of chlorophyll-a concentration together with meteorological data and tidal data which are acquired 7 months from October 2012 to April 2013, it is found that strong correlation between the truth data of chlorophyll-a and MODIS derived chlorophyll-a concentrations with R square value ranges from 0.677 to 0.791.

Also it is found that the relations between ocean wind speed and chlorophyll-a concentration as well as between tidal effects and chlorophyll-a concentration. Meanwhile, there is a relatively high correlation between sunshine duration a day and chlorophyll-a concentration.

As the results from the experiments, it is found that the followings,

- 1) *the accumulated sun appearances time duration is proportional to the truth data of chlorophyll-a concentration*
- 2) *it is confirmed that relation between ocean wind speed and chlorophyll-a concentration is weak,*
- 3) *it is confirmed that relation between sea surface level difference a day and chlorophyll-a concentration is weak,*
- 4) *it may said that relation between two days accumulated sea surface level difference a day and chlorophyll-a concentration is higher than that between one day sea surface level difference and chlorophyll-a concentration,*
- 5) *there is a time delay of chlorophyll-a increasing after the nutrient rich bottom seawater is flown to the sea surface.*

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