Monitoring of water pollution and aquatic plants in the coastal lagoon environments using ALOS data

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Abstract
Our research goal is to monitor the water pollution and aquatic plants in the coastal lagoon environments using satellite data. This time, our past activities concerning some satellite study project and the preliminary result of ALOS/AVNIR-2 analysis in coastal lagoon such as Lakes Shinji and Nakaumi are introduced.

Keywords: water pollution, aquatic plants, AVNIR-2, PALSAR, monitoring

1. INTRODUCTION

Lake Shinji and Lake Nakaumi are brackish lakes located in Shimane and Tottori Prefectures, Japan (Figure 1). As often seen in lakes near urban areas, these lakes are suffering eutrophication including the deterioration of water quality and occasional algal bloom occurrences. There is a strong social need for monitoring the water quality, understanding mechanisms that control physical, chemical and biological processes of the lakes, and mitigating the excess eutrophication. It is expected that satellite remote sensing can be a useful tool to conduct wide area mapping of the lakes through which 2-D distribution of various environmental parameters can be estimated. From these backgrounds, our past activities concerning some satellite study project, ALOS study plan and the preliminary result of ALOS/AVNIR-2 analysis in coastal lagoon such as Lakes Shinji and Nakaumi are introduced.

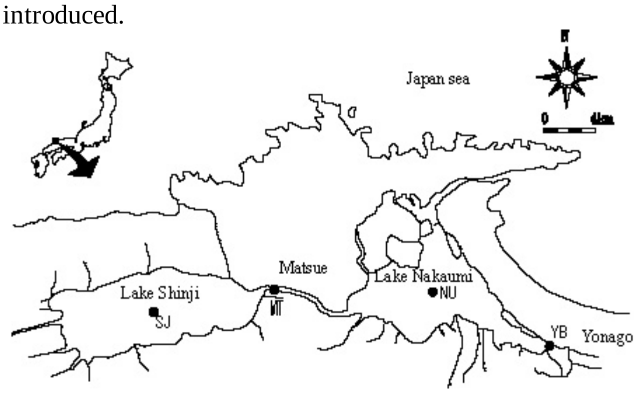

Figure 1. Map of study area with turbidity observation stations by Ministry of Land, Infrastructure and Transport Government of Japan.

2. Overview of our past activities

2.1. Chlorophyll-a estimation

Basic principle of water surface chlorophyll-a concentration (Chl-a) estimation is to measure the reflectance at visible and near-infrared waves from phyto-planktons near water surface. Spectral responses of the Chl-a in the plankton somewhat depends on the species of plankton. In the case of Lakes Shinji and Nakaumi, Chl-a is positively correlated with green band reflectance and negatively correlated with red band reflectance due to the absorption by Chl-a. Therefore, the reflectance ratio of green channel to red channel becomes a robust parameter to estimate Chl-a [1]. The other approach is to use multiple regressions to relate visible-to-near infrared spectral reflectance to Chl-a [2]. Figure 2 shows an example of Chl-a distribution derived from SPOT-2/HRV [1].

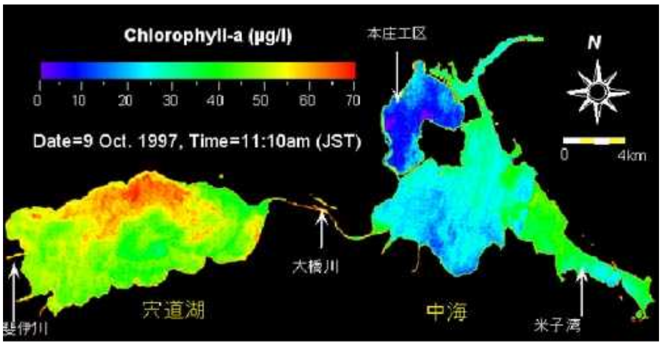

Figure 2. An example of Chl-a map derived from SPOT-2/HRV under algal bloom (Aoko) condition in the northern part of Lake Shinji, October 9, 1997. [1]

2.2. Turbidity estimation

Turbidity estimation is similar in principle to that to estimate Chl-a. The spectral response of inorganic materials is qualitatively similar over the visible to near-infrared bands, suggesting that any single wavelength measurement could be used for inorganic-origin turbidity estimation [3]. On the other hand, organic materials that also contribute to the turbidity have more complicated spectral response; i.e. absorption in red band. Therefore, the red band may not be suitable to turbidity estimation when organic materials are significant sources of turbidity. Our tentative conclusion is to use a near-infrared channel [2]. Figure 3 shows an example of turbidity distribution on May 2, 2002 derived from MODIS channel 2 (near-infrared) [4]. It is clear that turbidity is very high at west areas of the lakes, especially in Lake Shinji. This is probably caused by much rainfall of more than 30 mm in the previous two days which may cause much turbid water flow through Hii River, a major fresh water input to Lake Shinji. It should be noted that the single band estimation of turbidity is subject to errors caused by relative contribution of inorganic and organic-origin turbidity. Simultaneous estimation of Chl-a concentration would be essential to separate the two types of turbidity.

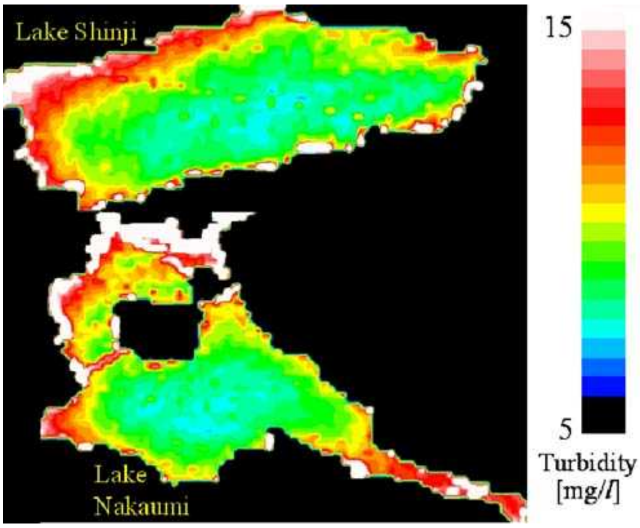

Figure 3. Turbidity distribution on May 2, 2002 derived from MODIS channel 2 (near-infrared) [4].

2.3. Surface temperature estimation

The estimation of surface temperature is performed by using thermal-infrared band, the principle of which is different from visible to near-infrared RS since it utilizes thermal emission from water surface, not the reflection of sun light. Until now we have employed ASTER TIR (Thermal Infrared) [5] for this purpose. The TIR has 5 channels in far infrared band, so precise atmospheric correction, important for high-accuracy surface temperature estimation, would be possible. By applying the multi-channel sea-surface temperature (MCSST) method developed by Matsunaga [6], we have obtained mean and RMS errors of -1.4 K and 1.1 K respectively, in comparison with in-situ observation as shown in Figure 3. The reason of -1.4 K offset is not yet clear; however, the difference in observation depth (in-situ: 1 to 2 m depth, RS: surface) may be one of the causes of the offset. Figure 4 shows an example of Lake surface temperature distribution on Aug. 7, 2000 derived from ASTER TIR 5 channels using MCSST algorithm [5].

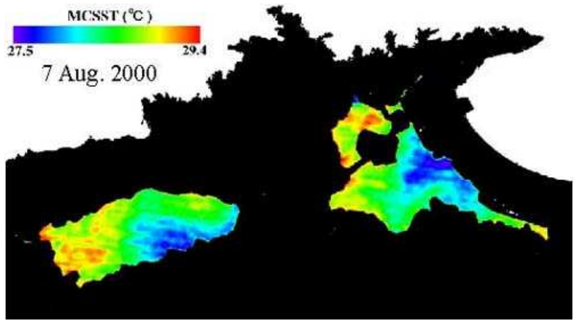

Figure 4. An example of Lake surface temperature distribution on Aug. 7, 2000 derived from ASTER TIR 5 channels using MCSST algorithm [5].

2.4. Wind speed estimation and detection of surface slicks

Surface wind is an important physical parameter that affects the surface water current and surface-bottom water mixing. Presently lake surface wind is estimated from measurements at meteorological stations around the lakes and a few tower measurements center of the lakes. It has been shown from many radar scatterometer measurements over ocean that radar return power at off-nadir incidence is essentially determined by the magnitude of small scale wind-driven wave so that back-scattering coefficient of the radar wave is proportional to the water wave spectral intensity. Spaceborne radar scatterometers are now used operationally to monitor sea surface wind field in a global scale. In the case of small lagoon areas such as Lakes Shinji and Nakaumi, however, the radar scatterometer cannot be used because of its very coarse spatial resolution of the order of several tens of kilometers. SARs are probably only spaceborne microwave instruments that can be used for such small lagoon areas. We have been studying the possibility of wind speed estimation using several spaceborne SARs [7]. It was found that RMS deviations of SAR-derived wind speed against in-situ data are between 0.4 m/sec to 3.5 m/sec depending on the type (wavelength and incidence angle) of SAR observation. The result indicates that shorter wavelength (shorter than 6 cm) and greater incidence angle (greater than about 30 degrees) are suitable for wind speed estimation.

Although the water surface roughness is generally determined by that due to surface wind which is the basis of wind speed estimation, in some cases, especially in weak wind conditions, SAR signatures are found to be more complicated than those expected from the wind field response. Such signatures have various shapes like “streak” and “cloud”. The cause of such signatures is yet to be clarified; however, we guess that thin surface slicks or ship wakes may be among the causes. One example taken on April 24, 1996, by ERS-1 SAR is shown in Figure 5. On this day we had strong westerly wind and SAR signatures show wind-wave response in the west area of the lakes; in the east areas, however, SAR response is strongly suppressed (dark areas), which is very strange when we consider the high wind speed of about 7-8 m/sec. One possible cause is that the strong westerly wind causes significant vertical water mixing [8]. In such case, bottom water upwelling may occur in the west side of the lakes, and the upwelled bottom water may move to the east by the eastward surface current, causing the accumulation of surface slick in the east side of the lakes. As a result, SAR response there may be significantly suppressed. To make clear the capability of the SAR detection of water surface slicks, a large amount of simultaneous in-situ and SAR measurements of water surface would be necessary.

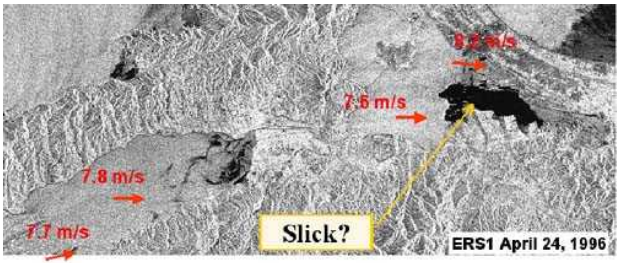

Figure 5. An example of SAR signature, taken on April 24, 1996, by ERS-1 SAR. Note that dark areas (especially in the east side of Lake Nakaumi) may be the indication of surface slick. Red arrows represent wind direction.

3. ALOS project plan

3.1. Overview

The purpose of this project is to construct the monitoring system of the pollution parameters (Chl-a, turbidity, etc.) and the aquatic plants in the coastal water region from 2007 to 2009. Moreover, the monitoring system of the water pollution and the aquatic plants in the coastal water region under cloudy condition using the ALOS/PALSAR data are also examined at the same time. Lake Nakaumi and Lake Shinji were chosen as a test site. Our project plan is shown in Figure 6.

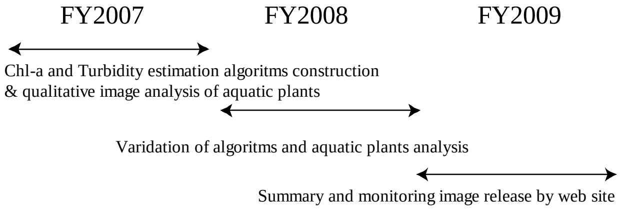

Figure 6. ALOS project plan from FY2007 to FY2009

3.2. Chl-a and turbidity estimation

Chl-a and Turbidity estimation algorithms are constructed using in-situ spectral reflectance data. The in-situ spectral reflectance/in-situ Chl-a and turbidity data set was collected by the ship investigation. The reflectance derived from the ALOS AVNIR-2 data is simulated from these data between 1995 and 2003. The correlation analysis between the simulated reflectance and the in-situ Chl-a or turbidity is done. The algorithm is verified in an actual ALOS/in-situ Chl-a or turbidity data set other day.

3.3. Aquatic plants analysis

The function of the plants in the river bed will be quantitatively evaluated with the satellite image, aerial photograph and field survey. The plants and animals in the river bed have a function of reducing the pollutant loads in the river. AVNIR-2 is used as the main sensor because of its color image, and PRISM is used as the supplement sensor because of its high image resolution. PALSAR image is also analyzed for the research purpose.

4. Preliminary result of ALOS analysis

4.1. Method and data

A preliminary result of turbidity estimation using cloud free ALOS AVNIR-2 data in Lakes Shinji and Nakaumi from 2006 to 2007 is introduced.

The satellite data used this time is L1B2 Geo Reference (CEOS format) data of the ALOS/AVNIR-2 sensor. The data was acquired for the period from August, 2006 to September 2007. In-situ turbidity data were also used. The in-situ surface turbidity data were acquired automatically at 11:00. As a result, seven in-situ turbidity data acquired on four days shown in Table 1 are used for the present analysis.

Table 1. Range of turbidity with satellite observations

Date	Turbidity (mg/l)	Number of sampling points
3 Aug. 2006	8-10	2
20 Feb. 2007	24	1
23 May 2007	1	1
21 Sep. 2007	2-8	3
Total	1-24	7

For the reflectance conversion from the ALOS data, the Eq.1 was used.

$$R_\lambda = (\pi [L_\lambda - L_{p\lambda}] d^2)/(ESUN_\lambda cos\theta_z) \qquad (1)$$

where, R is the effective at-satellite reflectance (unit less); L_λ is spectral radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$); Lp_λ is pathradiance ($Wm^{-2}sr^{-1}\mu m^{-1}$); d is the Earth-Sun distance in astronomical, $ESUN_\lambda$ is the mean solar exoatmospheric irradiance in $Wm^{-2}\mu m^{-1}$ at wave length λ; and θ_z is the solor zenith angle in degrees. Moreover, radiance conversion from digital value (DN) of the AVNIR-2 data was calculated based on Eq.2.

$$L_\lambda = a_\lambda DN_\lambda + b_\lambda \qquad (2)$$

where a and b show the gain and the offset of the radiance conversion coefficient respectively written by the header of the AVNIR-2 data. The ESUN and a used this time are shown in Table 2. Moreover, *b* is 0.

Table 2 Reflectance conversion parameters

Bands	a	ESUN($Wm^{-2}m^{-1}$)
1	0.588	1959
2	0.573	1851
3	0.502	1546
4	0.835	1061

4.2. Results

The correlation coefficient between the spectral reflectance derived from AVNIR-2 band before and after the offset removal, and turbidity are shown in Table 3. The correlation coefficients between the reflectances at Band 2 and Band 3 after the offset removal and turbidity are comparatively high. Figure 7 shows the correlation between reflectance at Band 2 with the highest correlation and turbidity (The estimation accuracy is 4.5mg/l). Figure 8 shows an example of turbidity distribution estimated from AVNIR-2 data using a simple regression algorithm (refer to Figure 7).

Table 3. Correlation coefficient between the reflectance of AVNIR-2 bands and the in-situ turbidity

	Band1	Band2	Band3	Band4
Before correction	-0.07	0.09	0.11	0.32
After correction	0.16	0.80	0.67	0.44

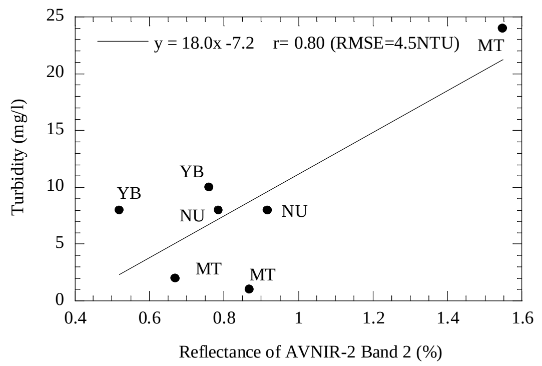

Figure 7 Correlation between the reflectance of AVNIR-2 Band 2 and the in-situ turbidity in Lake Shinji and Lake Nakaumi

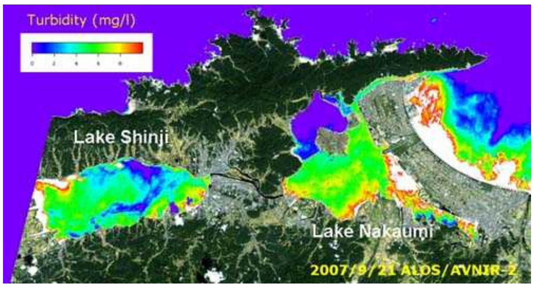

Figure 8. An example of turbidity distribution map on Sep 21, 2007derived from ALOS/AVNIR-2 Band 2 data.

Acknowledgement

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