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

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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. On the other hand, in the point of remote sensing technique, there was a big problem that the atmospheric correction was difficult for the water quality extraction using the satellite sensor with a high resolution such as LANDSAT/TM and ALOS/AVNIR-2.

From these backgrounds, we studied it with a title called “Monitoring of water pollution and aquatic plants in the coastal lagoon environments using ALOS data”. By the interim report, it was reported a policy and the turbidity estimate result of this study. By the finals report, a focus is narrowed down to the Chl-a estimate method by the LCI method mainly. In addition, I tried the analysis of the aquatic plant, but am left out here because enough result was not provided.

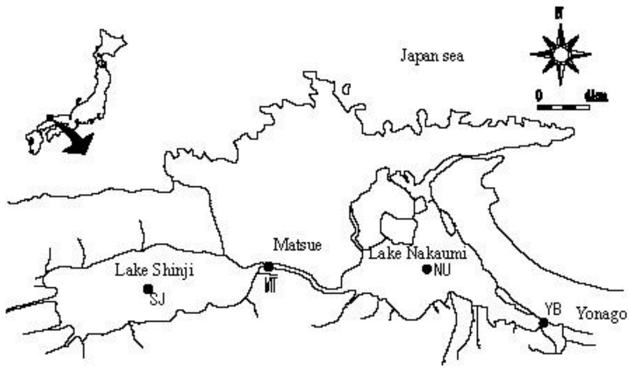

Figure 1. Map of study area with turbidity observation stations by Ministry of Land, Infrastructure and Transport Government of Japan.

2. LCI METHOD

The LCI (Linear Combination Index) method that Frouin et al [1] proposed was applied to the Chl-a estimate by the ALOS data in this study. The LCI method is easily explained here. The reflectance R_t which a satellite observes is expressed in the following approximate equation.

$$R_t(\lambda) = R_r(\lambda) + R_a(\lambda) + R_w(\lambda) \tag{1}$$

where λ is shown wavelength, the R_r and R_a are shown the reflectance of atmosphere molecules and aerosol reflectance, R_w is shown in-water reflectance. It is only Rw to be related with Chl-a in an Equation (1), and the remaining parameters become the noise. Because R_r in the Equation (1) is relatively easily calculated by atmospheric pressure, and so on, the Equation (1) is transformed as follows.

$$R_t(\lambda) - R_r(\lambda) = R_a(\lambda) + R_w(\lambda) \quad (2)$$

[R_t (λ)- R_r (λ)] in the Eqution (2) is expressed in other words with R_{tr} (λ) here. When it is defined the linear combination between plural bands of $R_{tr}(\lambda)$ as LCI, the LCI is expressed in the following equation.

$$LCI = \sum_{i=1}^{k} a_i R_{tr}(\lambda_i) = \sum_{i=1}^{k} a_i R_a(\lambda_i) + \sum_{i=1}^{k} a_i R_w(\lambda_i) \quad (3)$$

To eliminate most of the atmospheric influence on LCI has to find coefficients a_i that fulfill the following equation.

$$\sum_{i=1}^{k} a_i R_a(\lambda_i) = 0 \quad (4)$$

It is similar to the R_a in the following equation to set a coefficient "*a*" of Equation (4).

$$\sum_{i=1}^{k} a_i \lambda_i^{nj} = 0 \quad (5)$$

n_j is numerical value less than "number of the use bands -1" here. For example, in the case of a linear combination of 4 bands, the Frouin et al [#] used "n_j =0,-1,-2". In addition, in the case of the linear combination of 3 bands for the JAXA 500m resolution MODIS Chl-a of MODIS Near Real Time Data, ALOS LCI is expressed in the following equations was set using 3 bands (n_j =0.3,-1) and 4 bands (n_j =0,-1,-2) of ALOS.

$$LCI = R_{tr}(460) - 1.637R_{tr}(560) + 0.618R_{tr}(825) \quad (6)$$

$$LCI = R_{tr}(460) - 4.309R_{tr}(560) + 4.627R_{tr}(650) - 1.318R_{tr}(825) \quad (7)$$

Generally, Chl-a has a high correlation with LCI and is finally expressed in the following equation.

$$Chl - a = 10^{m \times LCI + n} \quad (8)$$

where, m, n are the fixed number. In these procedure, a function for Chl-a is made by LCI.

By the way, actually, at first a calculation of R_{tr} is necessary it is the procedure of Equation (1)-(7), and to lead an expression of relations of Chl-a and LCI from ALOS data.

A calculation procedure of R_{tr} is explained next. At first, the reflectance R_t each band is caluculated from the following equation.

$$R_t = \pi L / (F_0 \cos\theta_0) \quad (9)$$

L, F_0, θ_0 show radiance, solor irradiance and sun zenith angle. L of each ALOS band is converted into a radiance from DN (digital number) in the next equation.

$$L = (DN - 1) \times RCC \quad (10)$$

where, *DN*, *RCC* are a digital number, radiance conversion coefficients respectively. F_0, and representative *RCC* in this study are shown in list -1, list -2. In addition, detailed RCC is listed in the header of ALOS data.

After calculating a L_r using a linear expression of Turner [2], the R_r input it into an Equation (8). Only the summary of the equation is explained here because the calculating formula of the L_r is a very complicated equation. The L_r is calculated by *P* (air pressure), λ (wavelength), θ_0 (sun zenith angle), θ_r (sensor observation angle), τ_{O3} (optical thickness of the ozone), a function of ϕ (the magnetic declination between the sun and the sensor).

$$L_r = f(P, \lambda, \theta_0, \theta_r, \tau_{O3}, \phi) \quad (11)$$

Table 1 Solor irradiance

Bands	F_0(W/m^2/μm)
1	1943.3
2	1813.7
3	1562.3
4	1076.5

Table 2 Representative RCC parameters

Bands	a	b
1	0.588	0
2	0.573	0
3	0.502	0
4	0.835	0

3. DATA

The satellite data which I used are 6-day AVNIR-2 data shown in Table 3. In addition, a value of well-thought R_r is shown in table 4 from Equation (11) and Table 3. The input parameter (sun zenith angle, satellite observation angle) used header information of AVNIR-2 and air pressure data of the Japan Meteorological Agency observation. On the other hand, MODIS Chl-a data of the 500m resolution that JAXA provided and the relations of the actual value were examined, and it was estimated the actual value on an ALOS observation day by JAXA 500m MODIS Chl-a because actual survey Chl-a data in synchronization with AVNIR-2 were not provided this time. In addition, in the inspection of MODIS Chl-a data of the 500m resolution using in-situ Chl-a data (http://www.cgr.mlit.go.jp/izumokasen/) in Lake Shinji and Lake Nakaumi from February, 2007 to November, 2008 (16 data set). As for the comparison between LCI and Chl-a, considerably 500m resolution in AVNIR-2; after having resampled it, western part of Lake Shinji, heart of a lake, three points of the eastern part were compared in every day. Data set of MODIS Chl-a and in-situ Chl-a is shown in Table 4.

Table 3 Outline of ALOS data used

No	Date	Solar Zenith angle (deg.)	Pointing angle (deg.)
1	2006/8/3	24.3	0
2	2007/2/20	50.2	0
3	2007/5/23	20.3	0
4	2007/7/8	20.2	0
5	2007/9/21	37.1	0
6	2007/11/23	57.0	0
7	2009/6/26	19.1	0

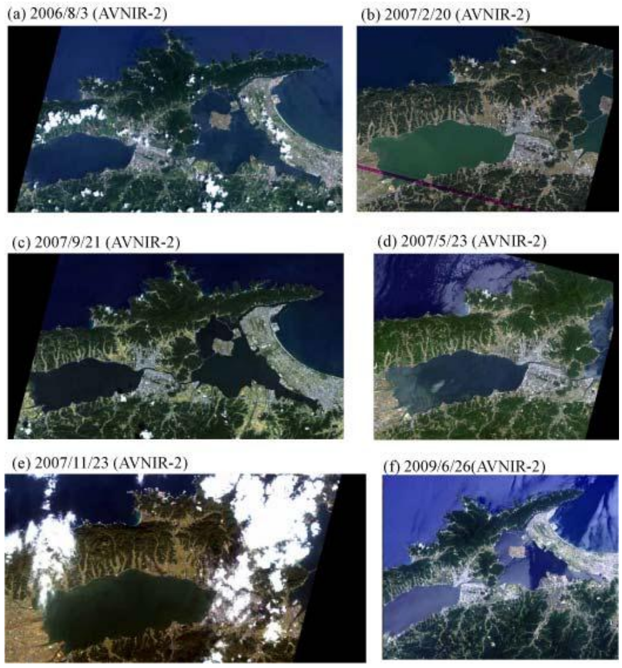

Figure 2 Index of ALOS data images used

Table 4 Lr calculated using Equation (11)

Date	*Band*	L_r(W/m^2/μm)
2006/8/3	1	39.0
	2	17.6
	3	8.7
	4	2.4
2007/2/20	1	39.6
	2	17.7
	3	8.6
	4	2.4
2007/5/23	1	38.8

	2	17.5
	3	8.7
	4	2.4
2007/7/8	1	38.5
	2	17.4
	3	8.6
	4	2.4
2007/9/21	1	39.0
	2	17.6
	3	8.6
	4	2.4
2007/11/23	1	40.2
	2	17.8
	3	8.7
	4	2.4
2009/6/26	1	38.7
	2	17.5
	3	8.6
	4	2.4

Table 4 Data set for the conversion from MODIS Chl-a to in-situ Chl-a

Date	St	DN	MODIS Chl-a	in-situ Chl-a
2007/2/7	NU	2461.3	3.7	11
2007/3/1	SJ	20206.4	30.3	53
2007/4/19	SJ	1548	2.3	19
2007/6/13	SJ	792.4	1.2	5.8
2007/9/12	NU	1927.1	2.9	11
2007/10/23	SJ	2776.3	4.2	22
2007/10/24	NU			9.1
2007/11/15	SJ	2465.6	3.7	23
2007/11/8	NU			7.5
2008/2/19	NU	2631.6	3.9	27
2008/4/14	SJ	34884.1	52.3	85
2008/4/21	NU	9931.4	14.9	27
2008/5/15	SJ	6428.8	9.6	15
2008/5/27	NU	3053.3	4.6	5.9
2008/7/15	SJ			11
2008/8/4	NU	1071.7	1.6	5.2
2008/9/11	SJ	3591.2	5.4	15
2008/9/1	NU			30
2008/10/8	SJ			15
2008/11/4	SJ	8290.2	12.4	23
2008/11/12	NU	5150.1	7.7	7.7

4. RESULT AND DISCUSSION

4.1 CONVERSION OF MODIS CHL-A TO IN-SITU CHL-A

A correlation between 500m MODIS Chl-a and in-situ Chl-a is shown in Figure 1. A significant correlation between 500m MODIS Chl-a and in-situ Chl-a (R=0.94) was observed. In the following equation, it was converted MODIS data of the ALOS observation day into in-situ Chl-a

$$Chl-a_{in-situ} = 7.7 + 1.4 Chl-a_{MODIS} \qquad (12)$$

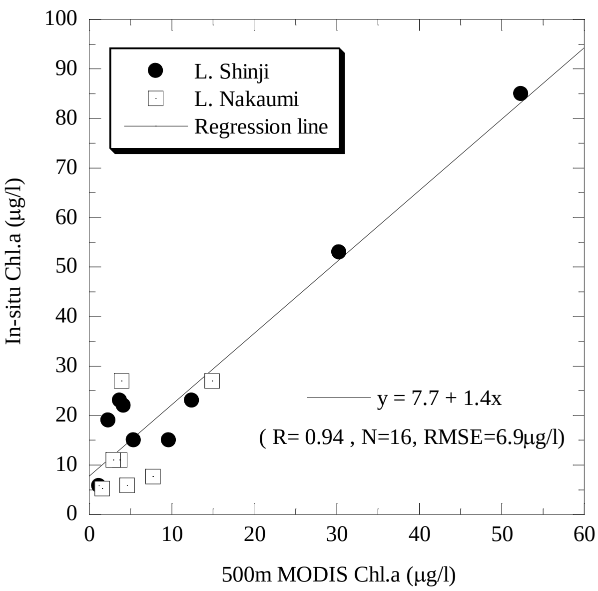

Figure 3 Relationship between 500m MODIS Chl-a and in-situ Chl-a

4.2 CORRELATION BETWEEN ALOS LCI AND CHL-A

Relationship between ALOS LCI and in-situ Chl-a are shown in Figure .4 using Equation (6) and Equation (7). LCI of Equation (7) was higher in correlation with in-situ Chl-a than this than LCI of Equation (6). As for this, it is thought that this is because it was able to reduce influence of the inorganic SS in lakes by adding reflectance of 650nm. The equation of relations between Chl-a and LCI which are finally led are as follows.

$$Chl.a = 10^{-32.4 \times LCI + 0.41} \qquad (13)$$

Chl-a estimation error (RMSE) was 2.0 μg/l calculated by Equation (13). In addition, an example of Chl-a distribution estimated by Equation (13) in Lake Shinji is shown in Figure 5.

5. CONCLUSIONS

In this study, feasibility of the new ALOS data use was considered for the monitoring of the turbid lakes such as Lake Shinji and Lake Nakaumi. In this report, the examination of the Chl-a estimation by the LCI method in particular was carried out. The main conclusions are as follows.

1)The LCI technique was applied to AVNIR-2, and the Chl-a estimation in these lakes was tried.
2)The LCI coefficient for AVNIR-2 was shown.
3)JAXA 500m MODIS Chl-a and measurement Chl-a had a high correlation.
4)A significant correlation between AVNIR-2 LCI and in-situ Chl-a calculated by 500m MODIS Chl-a data was obtained.

I am going to validate this algorithm using data set of other lake such as Lake Kausmigaura in future.

6. REFERENCE

[1]Frouin et al.: Retrieval of chlorophyll-a concentration via linear combination of ADEOS-II Global Imager data, Journal of Oceanography, Vol.62, pp.331-337, 2006.

[2]Turner, R. E. and Spencer, M. N.: Atmospheric model for correction of spacecraft data. In Proc. English Int. Symp. on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, Mich., pp. 895934, 1972.

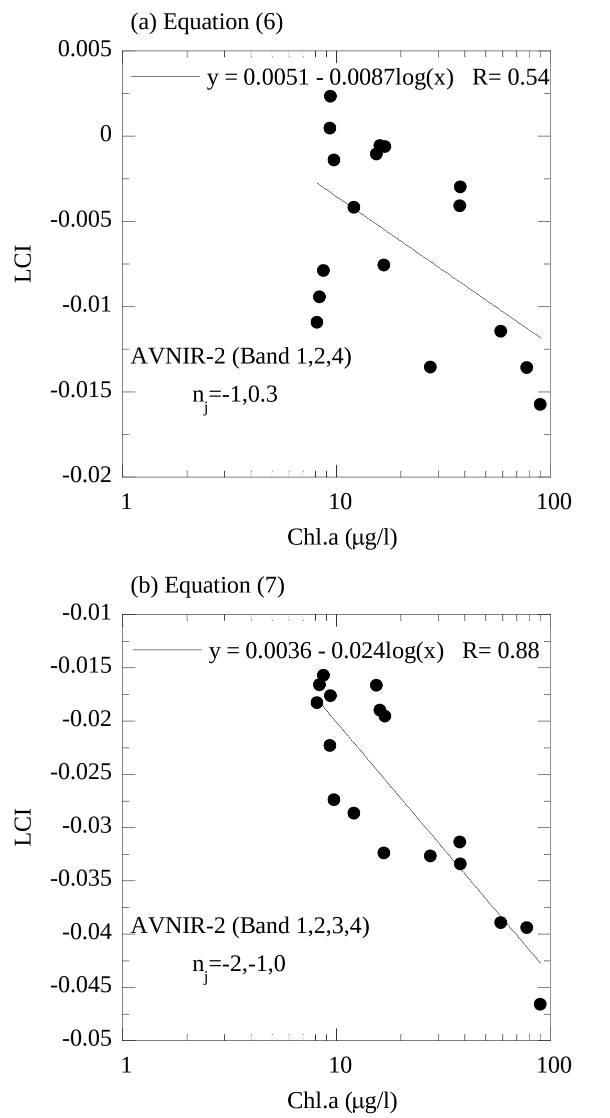

Figure 4 Relationship between LCI from AVNIR-2 using Eqation (6), (7) and in-situ Chl-a.

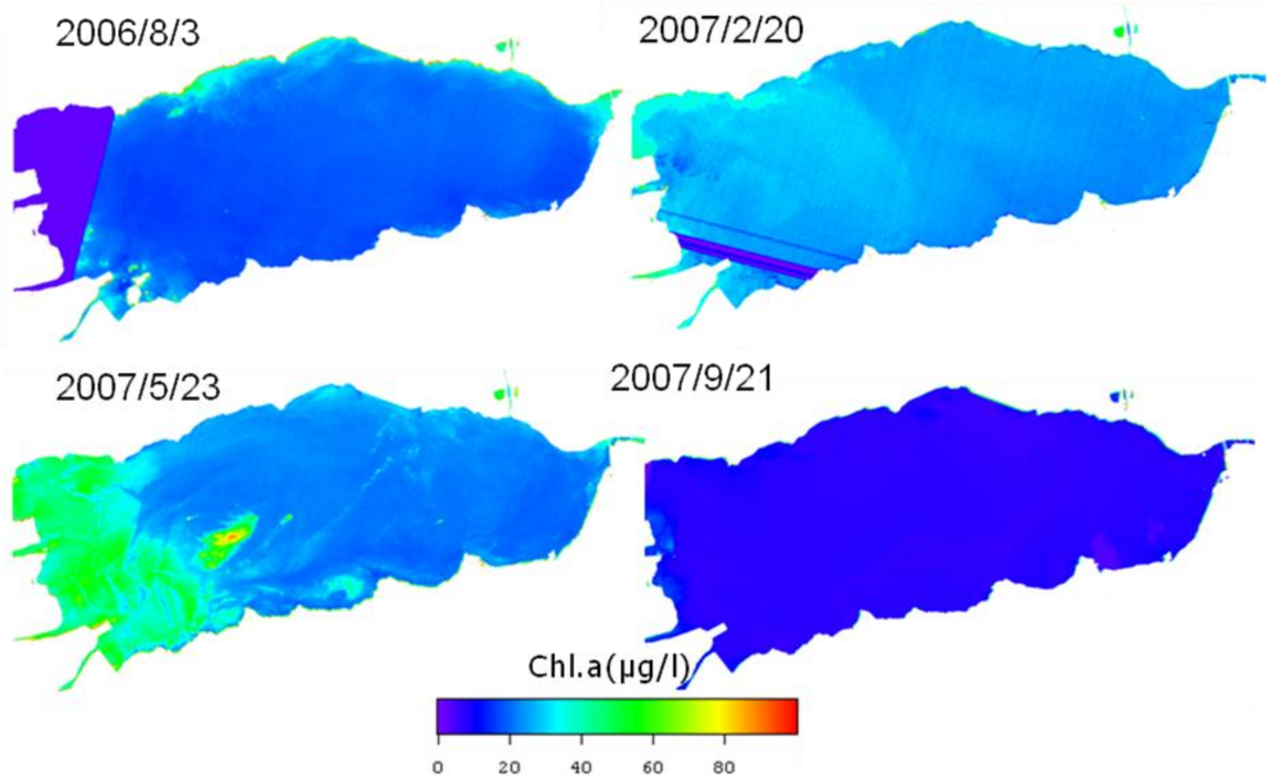

Figure 5 Example of Chl-a distribution estimated by Equation (13) in Lake Shinji

Appendix List of ALOS data acquired in Lake Shinji and Lake Nakaumi

No.	Sensor	Obs. Date	Product
1	PRISM	2006/6/18	L1B2
2	PRISM	2007/2/20	L1B2
3	PRISM	2007/5/23	L1B2
4	AVNIR-2	2006/8/3	L1B2
5	AVNIR-2	2007/2/20	L1B2
6	AVNIR-2	2007/5/23	L1B2
7	AVNIR-2	2007/7/8	L1B2
8	AVNIR-2	2007/9/21	L1B2
9	AVNIR-2	2007/11/23	L1B2
10	AVNIR-2	2007/11/23	L1B2
11	AVNIR-2	2008/1/8	L1B2
12	AVNIR-2	2008/1/8	L1B2
13	AVNIR-2	2009/6/26	L1B2
14	AVNIR-2	2009/9/26	L1B2
15	AVNIR-2	2010/11/11	L1B2
16	AVNIR-2	2010/12/1	L1B2
17	PALSAR	2007/6/14	L1B2

No.	Sensor	Obs. Date	Product
16	AVNIR-2	2010/12/1	L1B2
17	PALSAR	2007/6/14	L1B2
18	PALSAR	2007/7/30	L1B2
19	PALSAR	2007/9/14	L1B2
20	PALSAR	2007/9/19	L1B2
21	PALSAR	2007/10/6	L1B2
22	PALSAR	2007/12/18	L1B2
23	PALSAR	2010/8/10	L1B2
24	PALSAR	2010/8/27	L1B2
25	PALSAR	2010/9/11	L1B2
26	PALSAR	2010/9/19	L1B2
27	PALSAR	2010/9/25	L1B2
28	PALSAR	2010/10/12	L1B2
29	PALSAR	2010/10/23	L1B2
30	PALSAR	2010/10/27	L1B2
31	PALSAR	2010/10/30	L1B2
32	PALSAR	2010/12/1	L1B2