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Validation of Ocean Color Algorithms in the Ulleung Basin, East/Japan Sea

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Abstract : Observations were made to validate ocean color algorithms in the Ulleung Basin, East Sea in May 2000. Small scale and meso-scale surveys were conducted for the validation of ocean color products (nLw: normalized water-leaving radiance and chlorophyll concentration). There were discrepancies between SeaWiFS and in situ nLw showing the current aerosol models of standard SeaWiFS processing software are less than adequate (Gordon and Wang, 1994). Applying the standard SeaWiFS in-water algorithm resulted in an overestimation of chlorophyll concentration. This is because that CDOM absorption was higher than the estimated chlorophyll absorption. TSS concentration was also high. Therefore, the study region deviated from Case 1 waters. The source of these materials seems to be the entrainment of coastal water by the Tsushima Warm Current. Study of the bio-optical properties in other season is desirable.

Key Words : Validation, Ocean Color, Algorithms, Case 2,Normalized Water-leaving Radiance, Chlorophyll Concentration, CDOM.

1. Introduction

Accuracy of ocean color products is a prerequisite for application of ocean color. Such accuracy is ensured by calibration and validation. Ocean color data are processed in three steps: 1) Calculation of correct light intensity at the sensor in absolute physical quantity; 2) Removal of ocean atmospheric noises; and 3) Retrieval of ocean products, such as chlorophyll-a concentration. Therefore, cal/val of ocean color sensors are required at each procedure. The first procedure is calibration of sensor sensitivity either by onboard calibration mechanisms or by *in situ* measurements. In situ or vicarious calibration is done by comparing TOA (top of atmosphere) radiance and sensor outputs. This requires coincidental observation by satellite and by *in situ* measurement. The validation of the second procedure also requires coincidental observation while the third does not.

We attempted to validate the algorithms used in the above procedures for operating ocean color sensors such as Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Ocean Scanning Multispectral Imager (OSMI). We made a cruise in

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the Ulleung Basin in May 2000. In addition, we made a small scale coincidental observation near Mugho. TOA calibration measurements are described in another paper (Sohn *et al.*, 2000). Here, we report the results of our comparison of *in situ* and satellite derived normalized water-leaving radiance (nLw). We tried to validate the standard SeaWiFS in-water algorithm, which is also adopted for OSMI, by applying the algorithm to the measured nLw. Comparison was also made for the satellite chlorophyll values and *in situ* chlorophyll values.

2. Material and methods

A meso-scale cruise was made from May 17 through May 30 in 2000 in the Ulleung Basin (Fig. 1). At 18 stations, optical profiles were made using PRR600 (Bioshperical Co.) for downwelling irradiance and upwelling radiance at SeaWiFS bands. From these profiles, nLw (normalized water-leaving radiance) and Rrs (remote sensing reflectance) were calculated. Also chlorophyll-a, total suspended solids (TSS), and colored dissolved organic matter (CDOM) samples were

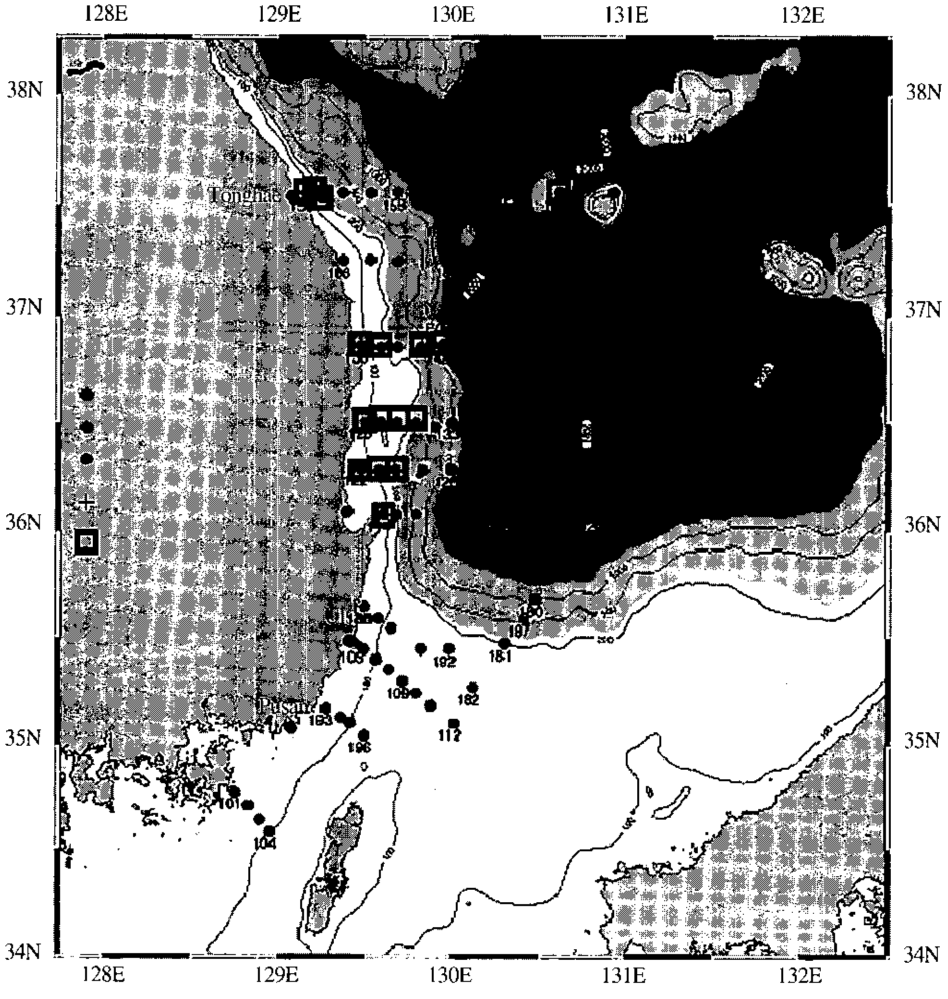

Fig. 1. Station map of May 2000 cruise. Rectangles are bio-optical stations.

taken. Chlorophyll-a was measured using Turner fluorometer model 10 on board the ship. The methods of TSS and CDOM absorption measurement are described elsewhere (KORDI, 1999). Profiles of T, S, chlorophyll fluorescence, beam attenuation coefficient and PAR were obtained by SBE25 (Seabird Co.).

On May 31, a survey was made at a location 10 km from the coast of Mugho for coincidental observation with SeaWiFS and OSMI (Fig. 2). Optical profiles were made using OCP (Ocean Color Profiler; Satlantic Co.). Comparison of satellite values and *in situ* values presents two difficulties: registration of correct pixel values with the exact location. Secondly, the difference in physical size of representing area: while the spatial resolution of typical current sensors is in the range of ~1 km, the point measurements made *in situ* represent bio-optical properties in at most tens of meters. Instead of comparing point-to-point, we obtained maximum likelihood estimators (MLEs) from 4 × 5 km plot and compared the MLE from the sea with that from satellite pixels. MLEs were computed assuming a lognormal distribution (Campbell, 1995) as follows:

$$X_{mle} = \exp(m+s^2/2)$$

where m and s^2 are maximum likelihood estimators for the mean and variance of ln X.

SeaWiFS chlorophyll-a values were derived from these, by using OC2 version 4 algorithm (O'Reilly *et al.*, 1998):

$$chl = 10^T + a(4)$$

where T and *a* given by

$$T = a(0) + ratio \cdot (a(1) + ratio \cdot (a(2) + ratio \cdot a(3)))$$

$$a = [0.319, -2.336, 0.879, -0.135, -0.017]$$

$$ratio = \log_{10}(Rrs490/Rrs555)$$

Chlorophyll absorption coefficient at the 490

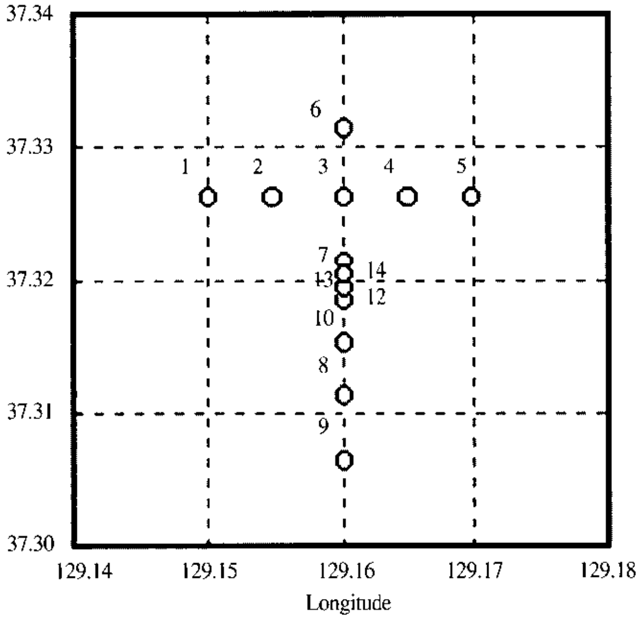

Fig. 2. Sampling points of coincidental observation made on May 31, 2000. Numbers indicate station numbers.

nm was estimated using Bricaud *et al.* (1995):

$a_{CHL}(490)=a^{*}_{ph}(490)\ \langle chl\rangle$

Chlorophyll-specific absorption coefficient at the 490 nm, $a^{*}_{ph}(490)$, can be estimated by

$a^{*}_{ph}(490)=0.0274\ \langle chl\rangle^{-0.361}$

where <chl> is *in situ* chlorophyll concentration. SeaWiFS data were processed using SeaDAS (SeaWiFS Data Analysis System) software (Fu *et al.*, 1998). Long-term monthly means of climatological data was used (Gregg *et al.*, 1993a,b).

3. Results

The nLw values observed in a small area within

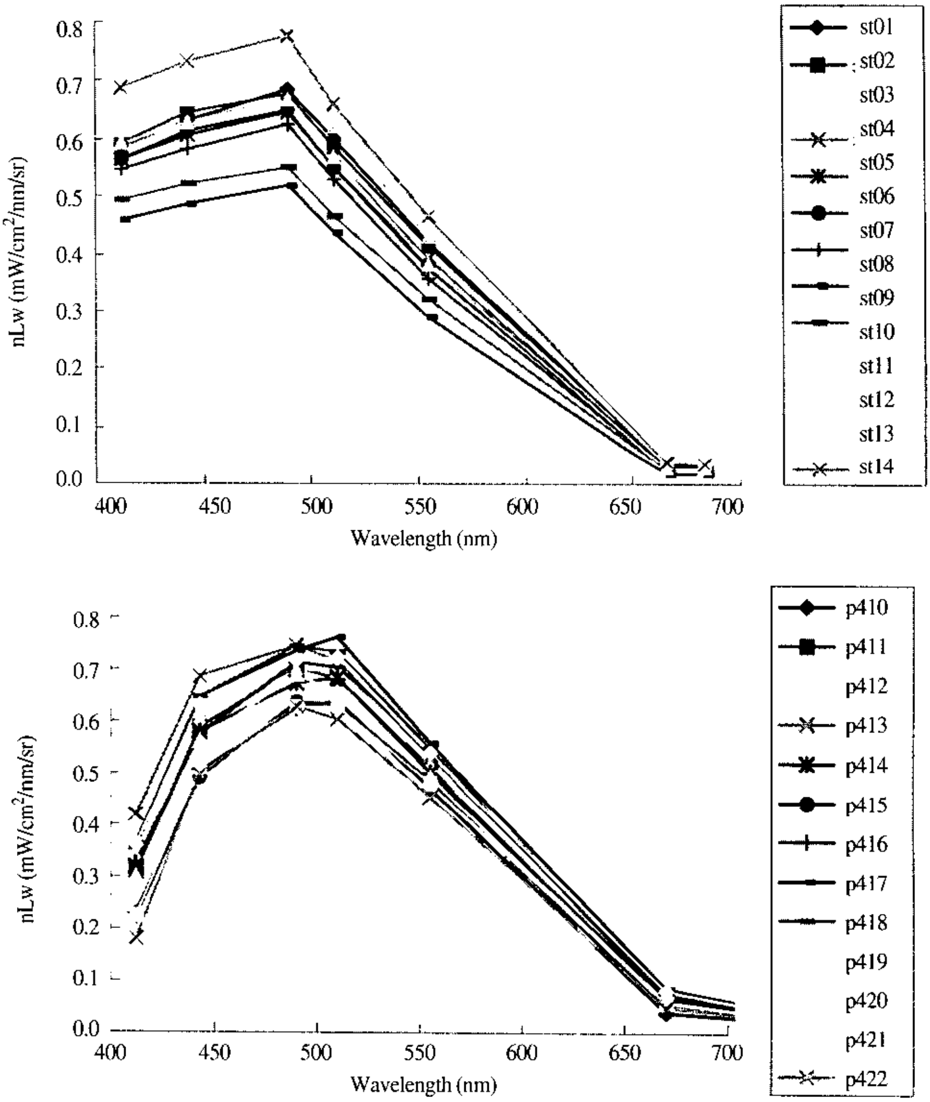

Fig. 3. Normalized water-leaving radiance observed *in situ* (upper panel) and from satellite (lower panel).

three hours of SeaWiFS over-passing show that there was an overall agreement in the magnitude between *in situ* and satellite nLw (Fig. 3). However, there is a severe deviation towards shorter bands, notably in 412 nm. This is, among other things, probably due to the lack of absorbing aerosol models in current version of SeaDAS.

Comparison of MLEs shows that the agreement is valid only in the 443 and 490 nm bands (Fig. 4). Underestimation occurs in 412 nm band while overestimation occurs in 510, 555, and 675 nm bands. Not only the inadequacy of aerosol model caused the discrepancy, but the hazy condition during the observation might have also contributed to the error.

The pattern of 18 remote sensing reflectance curves (Fig. 5) from the meso-scale survey does not show typical characteristics of case 2 water, i. e., shift of peak to longer wavelength (Morel and Prieur, 1977). Maxima lie in the blue bands. In some curves, a slight depression exits indicating the chlorophyll absorption is a major influence. However, evaluation of standard SeaWiFS algorithm for these reflectance values reveals substantial overestimation errors (Fig. 6). The relative error ranged 30.7~349.4% although RMS error was rather small (0.158) due to the fact that the chlorophyll concentration during the survey was low in the range of 0.07~0.37 mg m^{-3}.

Comparison of SeaWiFS chlorophyll with coincident *in situ* values gave a similar overestimation (Fig. 7). The relative error was 168~385% while RMS error was 0.337. The reason that the magnitude of error was rather similar between the *in situ* derivation and SeaWiFS chlorophyll is that the error in the atmospheric correction is significant in 412 band, while the SeaWiFS OC2 algorithm uses 490 and 555 nm.

Examination of the relationship between the chlorophyll concentration and Rrs(490)/Rrs(555)

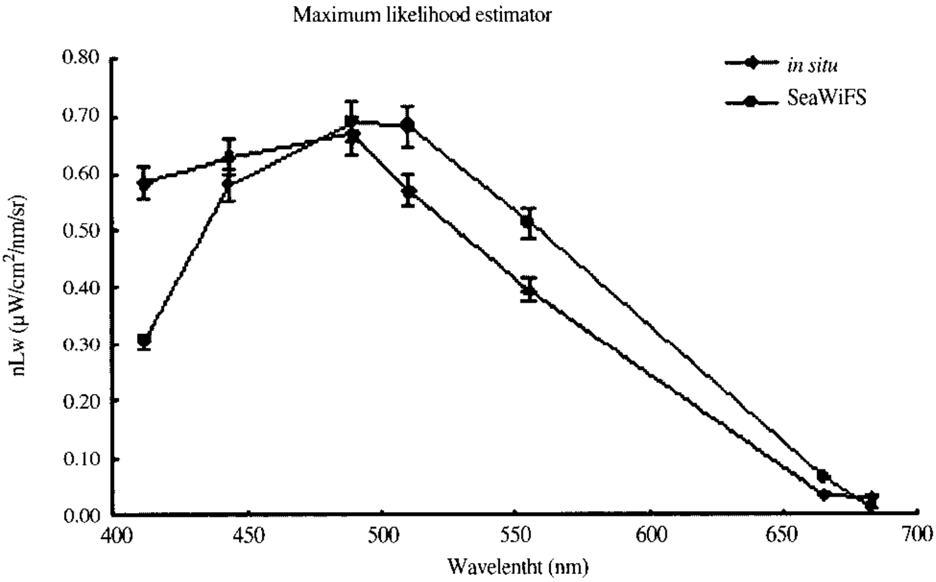

Fig. 4. Comparison of MLEs of SeaWiFS-derived and in situ nLw. Vertical bar at each point shows the 95% confidence interval of the means.

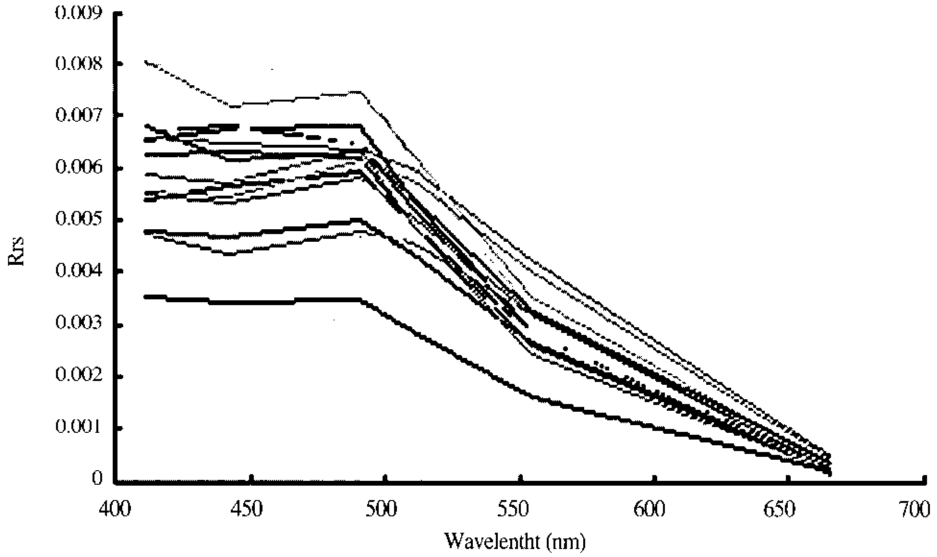

Fig. 5. Remote sensing reflectance spectra from the 18 stations.

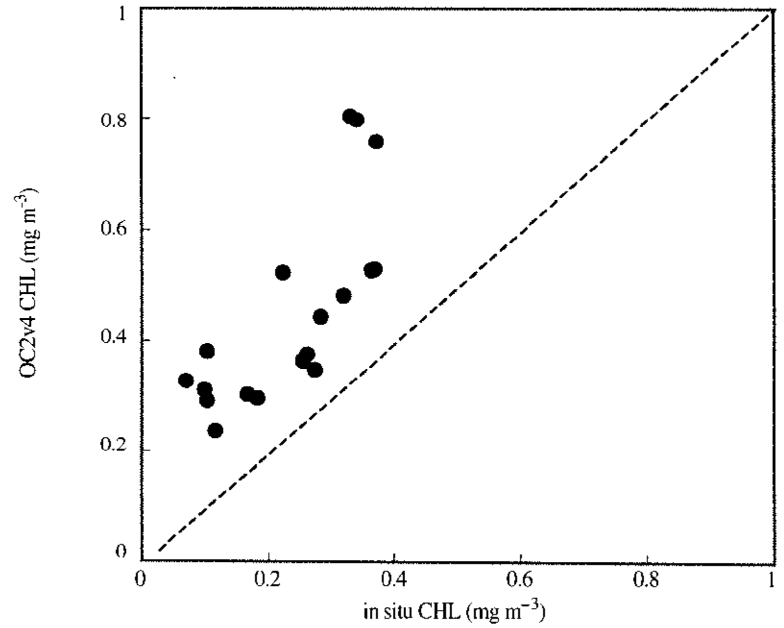

Fig. 6. Comparison of OC2 chlorophyll and *in situ* chlorophyll.

reveals that the ratio is consistently lower than expected by OC2 algorithm (Fig. 8). This is due to absorption by other materials than chlorophyll (Fig. 9). The range of CDOM absorption at 440 nm was 0.033~0.137 m^{-1}, which is rather high (Kirk, 1994). For example, at station 124, the $a_{CDOM}(490)$ was

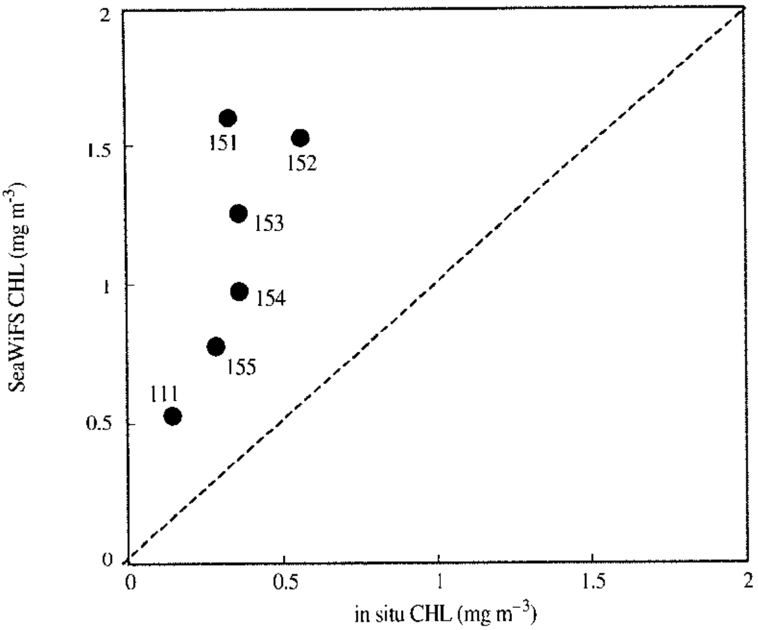

Fig. 7. Comparison of SeaWiFS chlorophyll and *in situ* chlorophyll.

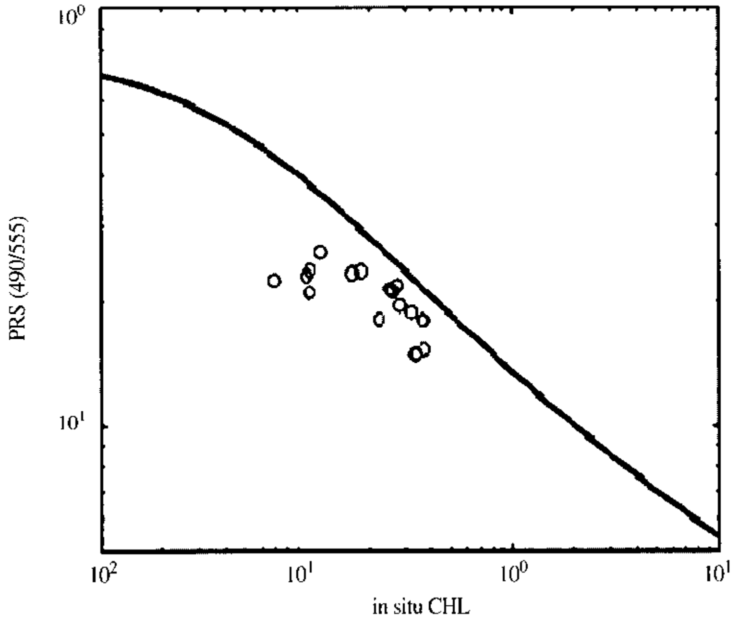

Fig. 8. Band ratio (490/555) versus *in situ* chlorophyll concentration. The line represents OC2 algorithm.

0.103 m^{-1} while $a_{Chl}(490)$ was estimated as 0.017 m^{-1} so that CDOM contribution in absorption was much higher than chlorophyll. TSS values also ranged 0.24~6.45 mg m^{-3}.

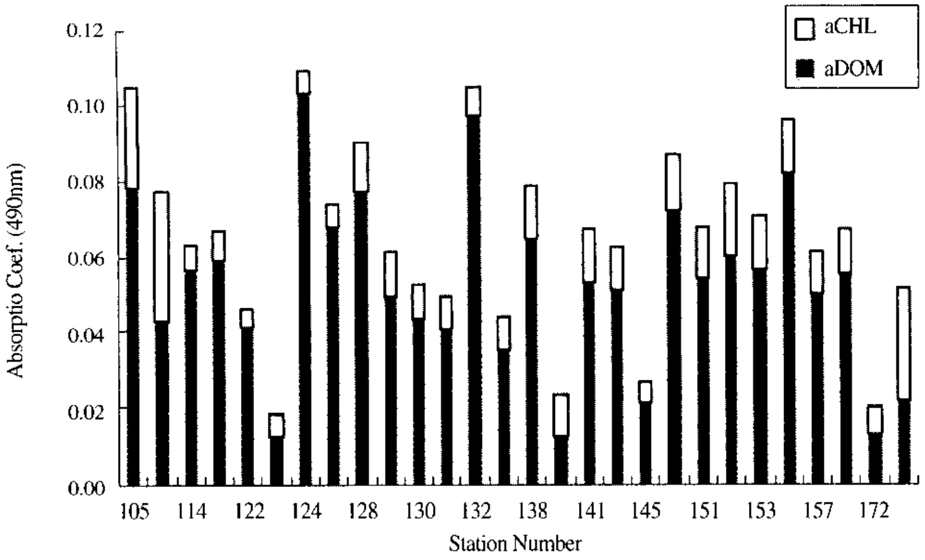

Fig. 9. Absorption due to CDOM and chlorophyll. Station numbers are the same as Fig. 1.

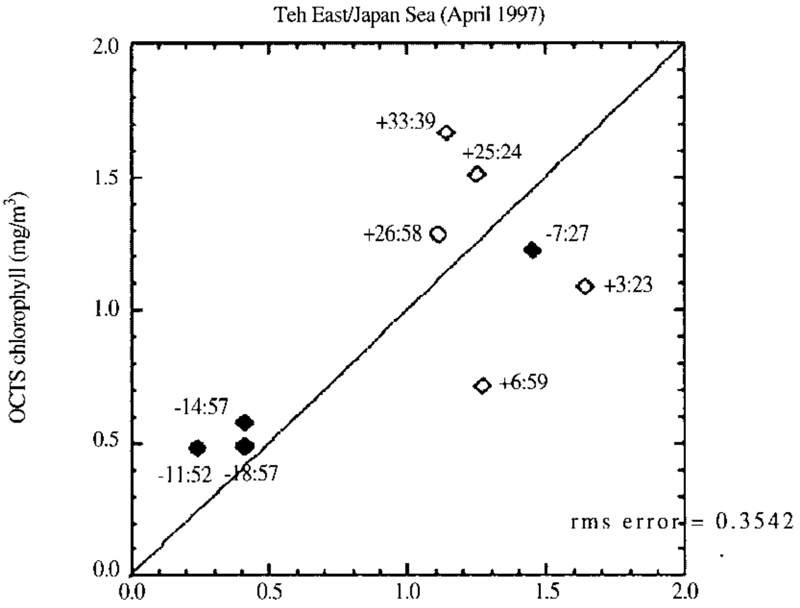

Fig. 10. Comparison of satellite (OCTS) chlorophyll and *in situ* chlorophyll concentrations.

4. Conclusions

East/Japan Sea has been assumed to be Case 1 waters given that there is no substantial river discharge and the shelf area is rather narrow while tidal difference is very small (~0.2 m). In situ chl-a data coincidentally collected with Ocean Color and Temperature Scanner (OCTS) in the

NOAA AVHRR SST 2000/523

Fig. 11. AVHRR/SST image showing the passing of Tsushima Warm Current.

open ocean of central East/Japan Sea seemed to confirm this assumption: There was a good 1:1 correspondence with little bias between the Case 1 chlorophyll values and *in situ* chlorophyll concentrations (Fig. 10; KORDI report, 1999). The RMS error was 0.3542 with 9 data points.

The numbers beside the data points indicate the time difference in observation.

However, the Ulleung Basin where the Tshushima Warm Current (TWC) enters might have different optical properties. Also in springs, as the TWC gets stronger, one of its branches typically flows along the Korean Peninsula forming meso-scale eddies (Hong *et al.*, 1983). In that process, coastal water of Korea could be entrained. In the satellite images, such currents and eddies can be identified by different SST or by enhanced reflectance in the visible bands. This could be due to substantial concentration of suspended sediments entrained or increased phytoplankton cell concentration due to nutrient entrainment. Probably the two processes occur simultaneously. If this is the case, this entrainment of other materials could influence the optical properties of seawater.

The SeaWiFS algorithms were basically derived from and intended for Case 1 waters. Since SeaWiFS algorithms were developed from a large database (919 datasets) for global application, the accuracy might be different depending on regional properties such as phytoplankton species composition (O'reilly *et al.*, 1998). However the consistent over-estimation observed here seems due to the entrainment of optically active materials other than phytoplankton pigments. Thus at least for the region surveyed here the optical properties seem to deviate from Case 1 waters.

The deviation is greater towards coastal area as expected. The major source of CDOM and TSS could be the coastal waters entrained into TWC. Fig. 11 is the AVHRR/SST image of May 23, 2000. Here a branch of TWC is shown to pass along the Korean coast and enter into the Ulleung Basin forming eddies.

The Yellow Sand from the Gobbi desert is known to pass through Korean Peninsula and Ulleung Basin (Fukushima and Ishizaka, 1993). It is particularly strong during springs. Although the amount of the Yellow Sand fallout in the Ulleung Basin is not known, it could affect the optical properties of the water.

It has been suggested that during summer Monsoon season, the discharges from the Changjiang river are transported to the East/Japan Sea by TWC (Kim and Roh, 1994). The diluted waters in the upper layer might stay in the region until deep vertical mixing occurs in winter. Thus during summer and autumn, optical properties could be influenced by Changjiang river discharge as well as Korean coastal waters.

Further surveys to observe seasonal changes in the spatial structure of the bio-optical properties in the region are desirable and will give interesting results.

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