Cross-validation of ocean color and sea surface spectral reflectance in the western equatorial Pacific Ocean

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Abstract
Cross-validation of ocean color represented as a chlorophyll-a concentration and sea surface spectral reflectance in the western equatorial Pacific Ocean is carried out not only to validate the model-derived chlorophyll-a concentration and surface reflectance estimates but also to propose an accuracy assessment method in terms of hyperspectral and operational context based on in situ sea surface spectral reflectance measurements onboard R/V Mirai and the optical water type classification model. The results of cross-validation indicate that model-derived estimates of chlorophyll-a and spectral reflectance are agreed well with in situ observed values. And the method proposed here can be utilized not only to validate the hyperspectal satellite-derived products but also to investigate the sensitivity of the satellite-derived products.

1. Introduction

Since Jerov proposed optical water types based on the spectral trasmittance of sea water in1976 (Jerlov, 1976), the classification of optical water type such as case 1(chloropyll-a dominated) and case 2 (suspended sediment dominated) water has been common among oceanographers and remote sensing scientists more than a decade. However the optically complex water type such as the water including colored dissolved organic matter (CDOM) has been found in coastal waters recently, the classification of optical water type needs to be further refined in terms of hyperspectral context. The purpose of the study is to propose an accuracy assessment method in terms of hyperspectral context based on the in situ sea surface spectral reflectance measurements onboard R/V Mirai and the optical water type classification model (Morel, 1988, Morel and Prieur, 1977) in the western equatorial Pacific Ocean.

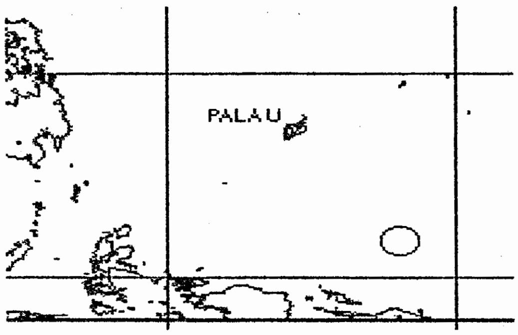

Fig.1 Study area with the stationary observation at 2N, 138E from Nov.22 to Dec.12,2002. (Circle represents the stationary observation area.)

2. In situ sea surface reflectance and chlorophyll-a concentration onboard R/V Mirai

Fig.1 shows the study area in the western equatorial Pacific Ocean. A circle indicates the stationary observation point of R/V Mirai at 2N, 138E during the MR02-K06Leg1 cruise from Nov.22 to Dec.12, 2002. During this period the ship was moving around the stationary point except the CTD (Conductivity-Temperature-Depth) profiler observations four times a day. Method of in situ observations include the measurement of sea surface spectral reflectance using the spectral radiometer GER1500, chlorophyll-a measurement and the other various meteorological and oceanographic parameters. Near-surface water at the depth of 4.5m is continuously pumped up at the rate of 200 litter per minute from the intake to the sea surface-monitoring laboratory (EPCS) for measuring fluorescence intensity.

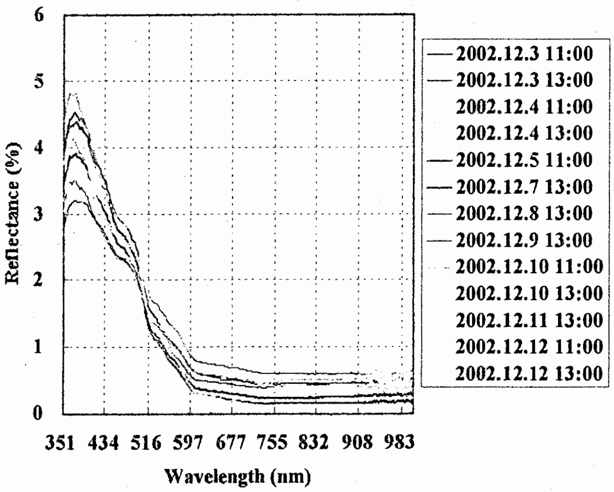

Fig.2 Spectral reflectance curves acquired from Dec. 3 to 12, 2002.

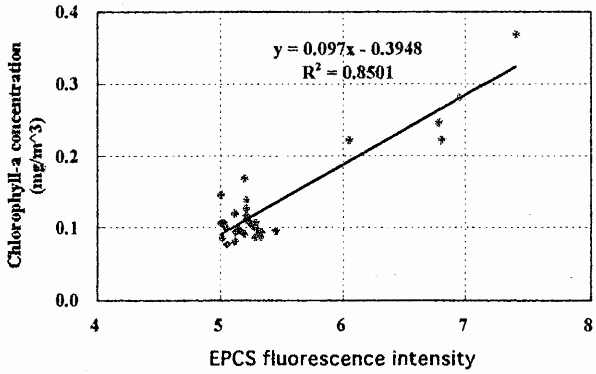

Fig.3 Relationship between EPCS fluorescence intensity and chlorophyll-a concentration.

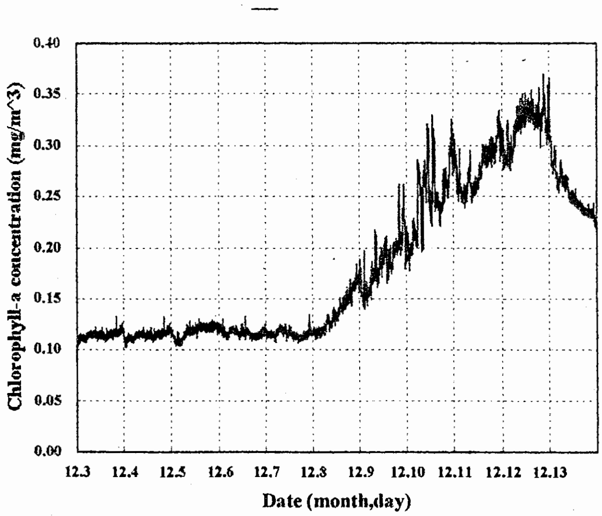

Fig.4 Variation of chlorophyll-a concentration based on EPCS fluorescence intensity.

Fig.2 shows the spectral reflectance curves of sea surface from Dec.3 to 12, 2002 observed by the spectral radiometer GER1500. The spectral reflectance reaches its maximum of 3.2 to 4.8 % at the wavelength of 370nm and its minimum at the one longer than 700nm. Since the electromagnetic energy in the near infrared wavelength region is absorbed at the sea surface, the high reflectance especially in the near infrared wavelength may be attributable to glittering or the reflectance from the breaking waves.

Fig.3 indicates the relationship between EPCS fluorescence intensity and chlorophyll-a concentration. Both parameters are positively correlated and show high squared-correlation coefficient. Based on this correlation continuous fluorescence intensity is converted to chlorophyll-a concentration described in Fig.4. During the first half of the cruise chlorophyll-a concentration is around 0.12 mg/m^3. After Dec.8 the concentration increases to the maximum of 0.36 mg/m^3 and decreases afterwards. Based on the SeaWiFS-derived chlorophyll-a products processed onboard R/V Mirai the increase of the concentration is caused by the high chlorophyll-a band associated with typhoon winds (Kozai and Miyake, 2003).

3. Method and Results

3.1 Estimation of sea surface reflectance based on the optical water type model and its validation

According to Morel (1988) the reflectance emerging from sea water is defined as the reflectance as observed just above the sea surface. This reflectance can be related to the reflectance Rw which is the ratio of the upwelling to downwelling radiance just below the sea surface as decribed below.

$$\rho_{sw}(\lambda) = \frac{Rw(\lambda) * t_d * t_u}{n^2 * (1 - 0.485 * Rw(\lambda))} \quad (1)$$

where Rw(λ) is the ratio of the upwelling to downwelling radiance just below the sea surface, t_d, t_u is the transmittance for downwelling and upwelling radiance respectively, and n is the index of refraction. Since the ratio Rw(λ) is dependent on the inherent optical properties of the sea water, such as the total absorption coefficient and the total backscattering coefficient, More and Prieur (1977) proposed the following approximation.

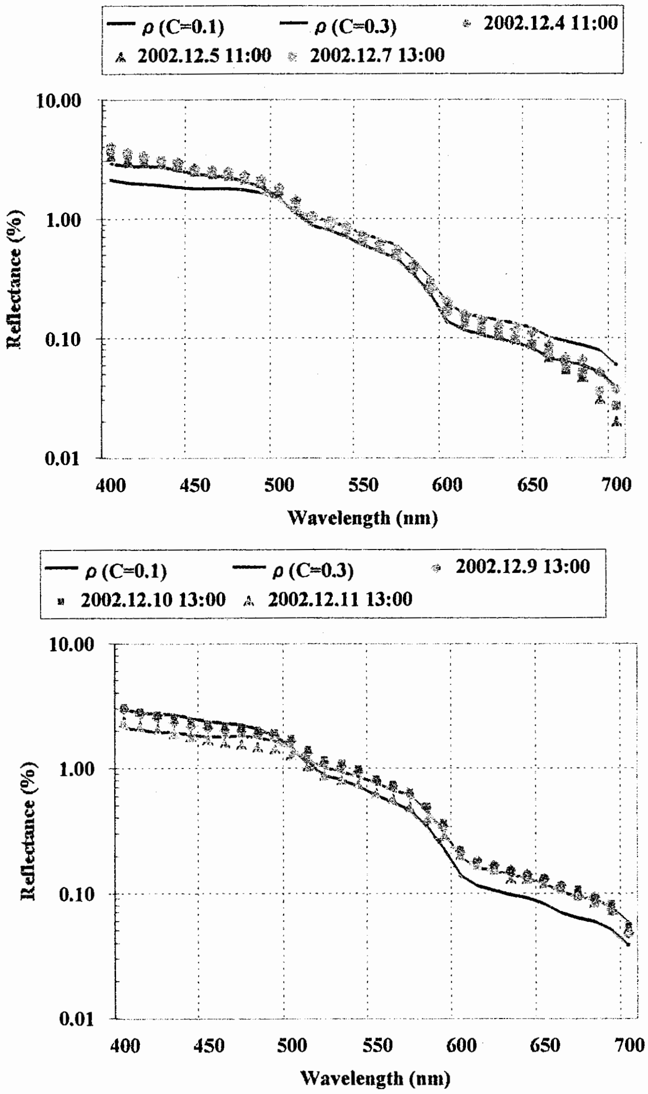

Fig.5 Comparison of sea surface spectral reflectances between the observed (dotted lines) and the estimated (solid lines) for three observations before (upper figure) and after (lower figure) Dec.8, 2002.

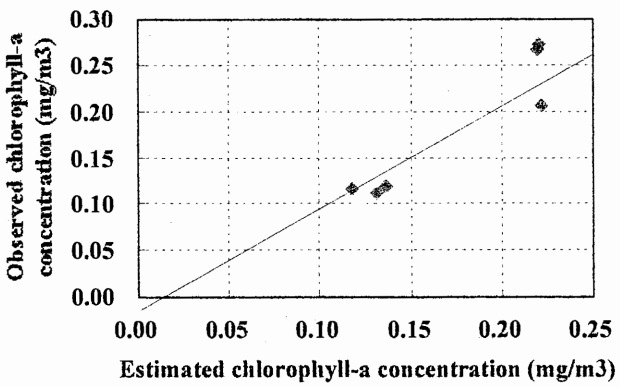

Fig.6 Comparison of chlorophyll-a concentration between the observed and the estimated.

$$Rw(\lambda)=0.33*b_b(\lambda)/a(\lambda) \quad (2)$$

where $b_b(\lambda)$ is the total backscattering coefficient and $a(\lambda)$ is the total absorption coefficient respectively. These parameters are also the functions of pigment concentration and diffuse attenuation coefficients. For the detailed relationship of the parameters please refer to Morel and Priur (1977) and Morel (1988). Based on the equations above sea surface spectral reflectances are estimated for validating the observed sea surface spectral reflectances acquired by the spectral radiometer GER1500. Fig.5 shows the comparison of sea surface spectral reflectances between the observed (dotted lines) and the estimated (solid lines) for three observations before (upper figure) and after (lower figure) Dec.8, 2002. Though the differences of chlorophyll-a concentration during both periods are very small, the estimated and the observed reflectances are corresponding well each other in terms of wavelength.

3.2 Estimation of chlorophyll-a concentration based on the SeaWiFS chlorophyll-a algorithm (OC4v4) and its validation

An algorithm of chlorophyll-a concentration estimation from SeaWiFS is used for validating the chlorophyll-a concentration acquired onboard R/V Mirai. The algorithm is called the Ocean chlorophyll 4-band algorithms version 4 (OC4v4) and it is defined as the fouth order polynomial equation as follows (O'Reilly et al., 1998, 2000)

$$C=10.0\^{}(0.366-3.067R_{4S}+1.930R^2_{4S}+0.649R^3_{4S}-1.532R^4_{4S}) \quad (3)$$

$$R_{4S}=\log_{10}(R^{443}_{555}>R^{490}_{555}>^{510}_{555}) \quad (4)$$

where C is the estimated chlorophyll-a concentration (mg/m^3) using the OC4v4 algorithms. R_{4S} represents that the ratio of 4 bands of SeaWiFS is utilized and the argument of the logarithm is a shorthand representation for the maximum of the three ratios. Upper and lower subscripts of R stand for the wavelength bands of SeaWiFS. Based on the algorithm above estimated chlorophyll-a concentrations are validated for the observed chlorophyll-a concentrations. Fig.6 indicates the result of comparison between the estimated and the observed chlorophyll-a concentrations. These parameters are agreed well each other except some higher concentration values.

4. Summary

Based on the results and discussion above the study is summarized as follows.

(1) Cross-validation between ocean color represented as a chlorophyll-a concentration and sea surface spectral reflectance in the western equatorial Pacific Ocean is carried out not only to validate the model-derived chlorophyll-a concentration and surface reflectance estimates but also to propose an accuracy assessment method in terms of hyperspectral and operational context based on in situ sea surface spectral reflectance measurements onboard R/V Mirai and the optical water type classification model.

(2) The results of cross-validation indicate that the estimated and the observed reflectances are corresponding well each other in terms of wavelength. On the other hand the result of comparison between the estimated and the observed chlorophyll-a concentrations are agreed well each other except some higher concentration values.

(3) The method proposed here can be utilized not only to validate the hyperspectal satellite-derived products but also to investigate the sensitivity of the satellite-derived products.

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