# Seasonal Variation of Attenuation Coefficient Spectra Extracted from Yamato Bank Optical Moored Buoy Data

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**Abstract**

Seasonal variation of attenuation coefficient spectra in Japan sea was extracted from underwater radiance/irradiance spectra observed by a moored buoy system developed by National Space Development Agency of Japan (NASDA). The buoy was deployed 9 months from August 31, 1996 to June 1, 1997. Throughout this period, it was collecting downward irradiance and upward radiance spectra under water at the depth of 1.5m and 6.5m everyday. The dairy averaged diffused attenuation coefficient spectra and underwater reflectance spectra were calculated. The results were compared with the absorption spectra of filtered samples obtained by validation cruises, which carried out 5 times during the moored period. Also, the natural fluorescence of chlorophyll a were extracted from the upward radiance spectra observed at 1.5m depth. The seasonal variation of the calculated attenuation coefficient spectra and the natural fluorescence were examined. The result shows a weak blooming of phytoplankton on November and a large blooming on April.

**Introduction**

The Ocean Color and Temperature Scanner (OCTS) on board the Advanced Earth Observing Satellite (ADEOS) was operated from August 1996 to June 1997 when the satellite was accidentally terminated. In order to verify the outputs of OCTS, the National Space Development Agency of Japan (NASDA) deployed a dedicated moored buoy system at the Yamato bank in the Japan Sea, 39°24'06"N, 135° 05'16"E, (Figure 1) from August 31st, 1996 to June 1st, 1997. The buoy, called YBOM (Yamato Bank Optical Moored Buoy), equipped an underwater spectro-radiometer and provided daily radiance/irradiance spectra for 6 months continuously. A part of the data were used for the calibration of visible bands of the OCTS, however the whole period of data set contain a lot of information for the future applications of ocean color remote sensing. In this paper, we have analyzed this data set and extracted several optical properties concerning the blooming of phtoplankton in the Japan Sea.

**Characteristics of the Data Set Obtained by YBOM**

Figure 2 shows a schematic view of the YBOM. It was designed for the calibration and validation of the OCTS as well as the NASA scatterometer (NSCAT) which also equipped on the ADEOS, so that it provided not only spectroradiometer but also a fluorometer detecting chlorophyll fluorescence and meteorological sensors such as temperature, humidity, wind and wave [Matsumura at al., 1992; Ishizaka et al., 1996; Kishino et al., 1997]. Total length and net weight are 13.6m and 5.9 ton, respectively. Five light collectors are mounted to observe the incident solar radiance *Es* at 5m above the sea surface, underwater downward irradiance *Ed* and upward radiance *Lu* at depths of 1.5m and 6.5m. The light comes on each collector was led to the spectroradiometer one by one cyclically. The spectroradiometer contains dual polychromators equipped with linear photodiode array detectors, so that two regions of continuous spectra were obtained for each collector; short wavelength region from 400nm to 620nm and long wavelength region from 580nm to 800nm. It provide with 2 nm spectral interval and 6nm spectral resolution. In order to certify the sensitivity, exposing time was controlled by regions and collectors shown in Table 1. It results 3min 35 sec for a series of radiance/irradiance data collection. The observation was carried out from 0900 to 1500 local time ( 9 hours ahead of the universal time) with the interval of 1 hour, and from 1100 to 1400 with 20 minutes interval. The spectoradiometer including five collectors were calibrated before the deployment by using a standard lamp evaluated by National Institute of Standards and Technology (NIST). Chlorophyll fluorescence and meteorological parameters were collected every 2 hours from 0100 to 2300.

Most of observing parameters including radiance and irradiance were collected through 6 months. However we couldn't obtain a chlorophyll fluorescence, atmospheric temperature and water temperatures after 2 months from the deployment because of electrical troubles.

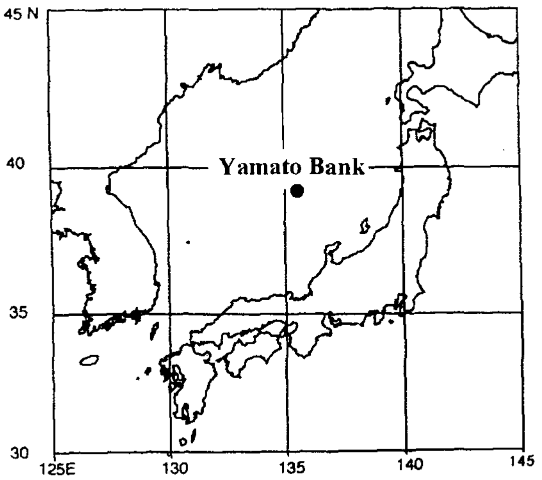


Fig.1 Moored location of YBOM

Table 1 Exposure time for each collector channel

| Collector Channel | Exposure Time (sec) | |
|---|---|---|
| | 400 - 620 nm | 580 - 800 nm |
| Es(λ)<br>Ed1.5(λ), Ed6.5(λ) | 2 | 2 |
| Lu1.5(λ), Lu6.5(λ) | 5 | 48 |

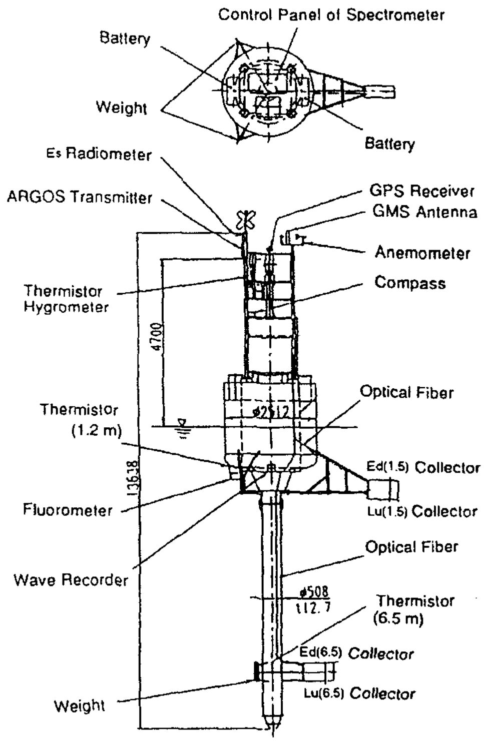


Fig.2 Schematic diagram of the YBOM

**Extraction of Optical Properties**

Optical properties of upper ocean are characterized by the absorption *a(λ)* and back-scattering *bb(λ)* of particulate matters including phytoplankton, dissolved organic matters and water. An attenuation coefficient *k(λ)* and a reflectance *R(λ)* under water are directly related with these parameters, and then show the inherent optical properties of upper ocean.

An attenuation coefficient between 1.5m and 6.5m depths observed at the time t is calculated as

$$k(\lambda,t) = -\frac{1}{6.5-1.5}\ln\left\{\frac{Ed_{6.5}(\lambda,t)}{Ed_{1.5}(\lambda,t)}\right\} \qquad (1)$$

The value of *Ed6.5(λ,t)* sometime contains severe noise especially under a rough weather, which results noisy *k* spectrum. In order to reduce the noise, we calculate a daily average of *k* as follows under the assumption that *k* value is constant through one day in the open ocean.

$$k_{av}(\lambda) = \frac{1}{n}\sum k(\lambda,i) \qquad (2)$$

where *i* corresponds to the observation time and *n* is the number of averaged spectra (1=<n=<13). Here we remove low intensity $Ed6.5(\lambda,t)$ because it enhances the noise.

$k(\lambda)$ is expressed as a simple sum of the absorption and back-scattering, and moreover, contributions from particulate matters $kph$, dissolved organic matters $kd$ and pure water $kw$.

$$k(\lambda) = a(\lambda) + bb(\lambda) = kph(\lambda) + kd(\lambda) + kw(\lambda) \qquad (3)$$

Then the inherent optical property of the ocean appears in $k$ - $kw$. Further more, $kw$ is assumed as the sum of the absorption $aw$ and the back-scattering $bw$. In this paper we use the precisely measured result by Pope and Edward (1997) for $aw(\lambda)$, and Morel and Prieur's result (1977) for $bw$ by linearly interpolated into the spectral interval of 2nm.

An underwater reflectance at 1.5m depth is calculated as

$$R(\lambda,t) = \frac{Lu_{1.5}(\lambda,t)}{Ed_{1.5}(\lambda,t)} \qquad (4)$$

A daily average of the reflectance $Rav(\lambda)$ is also calculated same as (2).

The reflectance is simply expressed as

$$R(\lambda) = \frac{1}{Q \cdot f} \frac{bb(\lambda)}{a(\lambda)+bb(\lambda)} \qquad (5)$$

where $Q$ indicates a radiance to irradiance ratio (=4 ~ 5) and $f$ is a constant (=3). However, $Lu(\lambda)$ contains natural fluorescence of chlorophyll a in the red region (650-700nm), it appeares as a peak in $R(\lambda)$ . This natural fluorescence is extracted by integrating the peak in $Lu(\lambda)$, and divided by photosysthetically available radiation as follows,

$$F = \frac{\int_{650}^{700} Lu1.5(\lambda)d\lambda - B}{\int_{400}^{700} Ed1.5(\lambda)d\lambda}, \quad B = \frac{Lu1.5(650)+Lu1.5(700)}{2*(700-650)} \qquad (6)$$

**Results and Discussion**

During the 9 months mooring period, validation cruises were carried out 5 times, where the vertical distribution of chlorophyll concentration and underwater radiance/irradiance were measured close by the buoy. Table 2 shows the list of chlorophyll a concentration observed by these cruses. Chlorophyll concentration is quite high in April, and a little high in November. In contrast with them, it is very low in September. Figure 3 shows absorption spectra of the filtered sample obtained on the cruise by using Whatman GF/F glass fiber filter. The spectra are regularized at the absorption peak of chlorophyll a, 675 nm, which correspond to the concentration of chlorophyll a. It is clear that the absorption at blue region become higher against the lower chlorophyll concentration.

Table 2 Concentration of chlorophyll a observed by validation cruises (ug/L)

| Date | 0m | 5m | 10m | 20m | 30m | 50m |
|---|---|---|---|---|---|---|
| 96/Aug/31 | 0.03 | 0.02 | 0.02 | 0.05 | 0.11 | 0.18 |
| 96/Sep/19 | 0.09 | 0.08 | 0.05 | 0.15 | 0.18 | 0.34 |
| 96/Nov/15 | 0.30 | 0.31 | 0.28 | 0.31 | 0.31 | 0.09 |
| 97/Apr/15 | 1.67 | 1.53 | 1.29 | 1.59 | 0.58 | 0.08 |
| 97/Jun/1 | 0.15 | 0.15 | 0.13 | 0.17 | 0.25 | 0.51 |

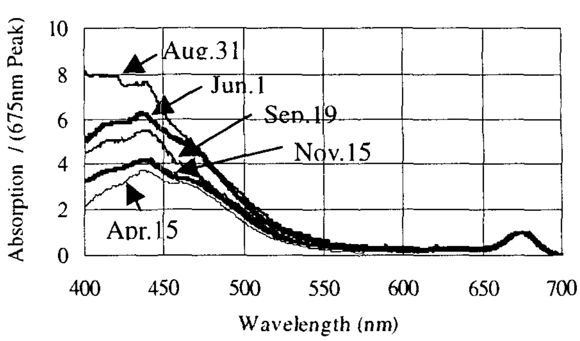


Fig.3 Absorption spectra of the filtered sample obtained by the validation cruises. Sampling depth was 5 m. All spectra are regularized at the chlorophyll a absorption peak, 675 nm.

Figure 4 shows an example of observed radiance/irradiance spectra (at 1200 on April 15, 1997). Each spectrum has double values from 580 to 620 nm because of the overlapping of array detectors. A fluorescence peak is cleary found in $Lu(\lambda)$ from 650 to 700 nm.

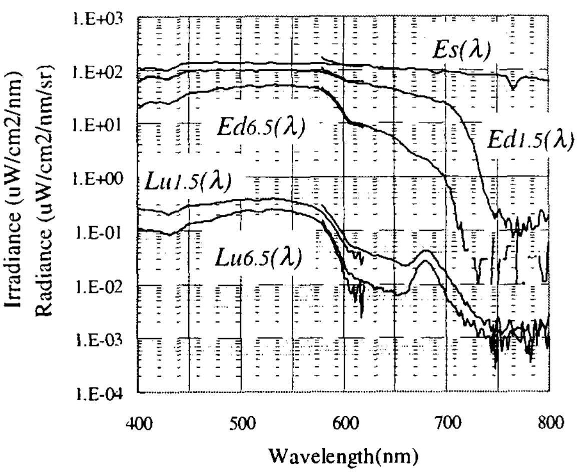


Fig.4 Spectral radiance and irradiance collected by YBOM at 1200 on April 15,1997.

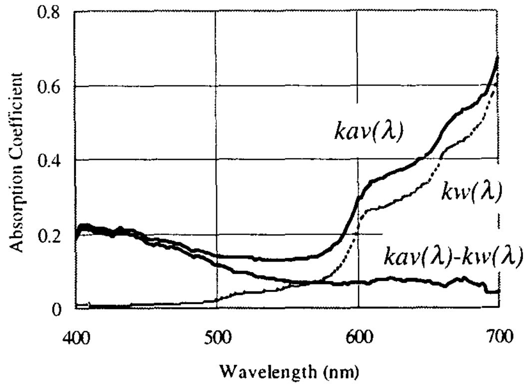


Fig.5 Attenuation coefficient $k$, and $k$-$kw$ for the data obtained at 1200 on April 15, 1997.

Figure 5 shows a dairy averaged attenuation coefficient *kav(λ)* and *kav(λ) -kw(λ)* on April 15, 1997. Features of chlorophyll absorption are recognized in *kav(λ) -kw(λ)*. The region longer than 700 nm is neglected because both *Ed1.5(λ)* and *Ed6.5(λ)* contain severe noise.

Figure 6 and 7 show dairy averaged inherent attenuation coefficient, *kav(λ) -kw(λ)* and reflectance, *R(λ)* at different seasons. On April, corresponding to the results of Table 2, the absorption becomes higher and reflectance falls remarkably in the blue region. Moreover, the natural fluorescence intensity appeared around 680nm in the reflectance spectra becomes noticeable on April. It is obvious that the spectral shapes of *kav(λ) - kw(λ)* in short wavelength region less than 450nm are relatively higher than the absorption spectra shown in Fig.3. It suggests a large contribution of dissolved organic matters.

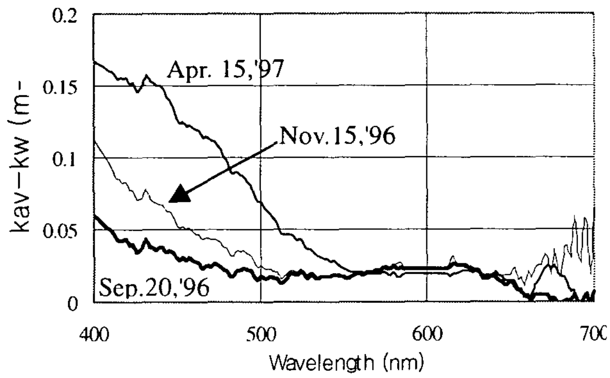


Fig. 6 Dairy averaged inherent attenuation coefficient, *kav(λ) -kw(λ)*.

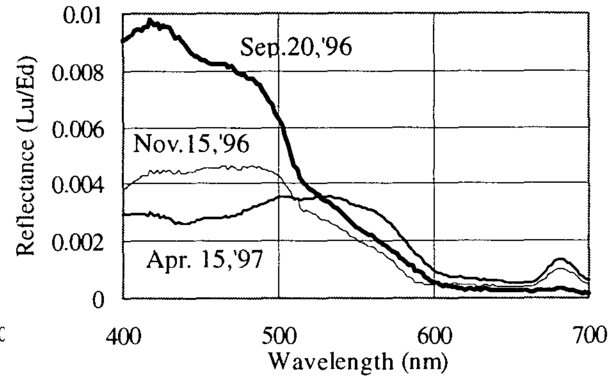


Fig. 7 Dairy averaged reflectance, *R(λ)*.

Time series of the natural fluorescence dirived by equation (6) is shown in Figure 8. A small blooming is found from November to December, and a concentrated blooming in April. The same phenomena are noticed in the inherent attenuation coefficient spectra shown in Fig. 9 and 10. Attenuation coefficient correspond to the absorption maximum of chlorophyll a (440nm) shows clear coincidence with the trend of natural fluorescence.

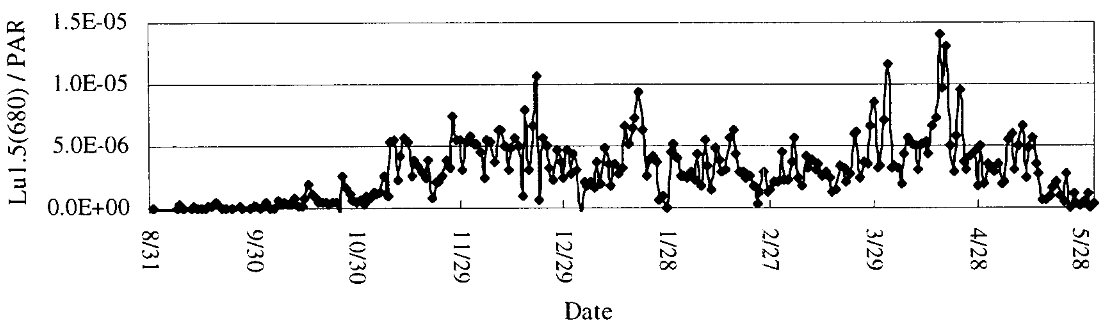


Fig.8 Time series of the natural fluorescence derived by eq.6.

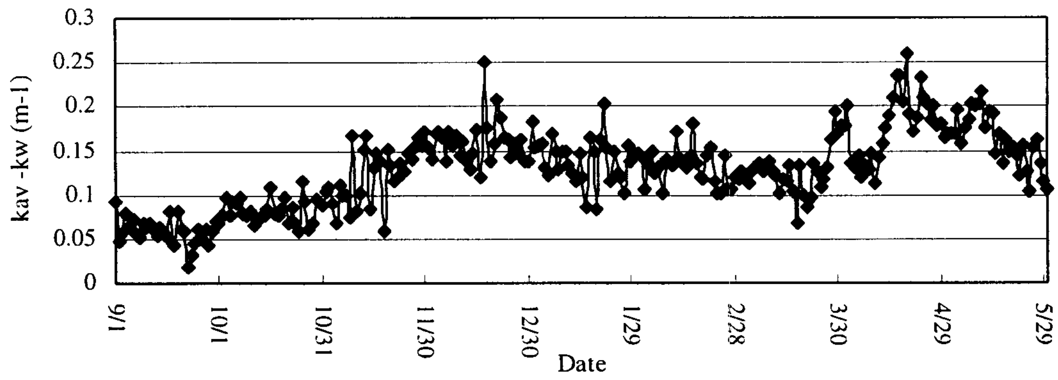


Fig.9 Time series of the inherent attenuation peak at 440nm.

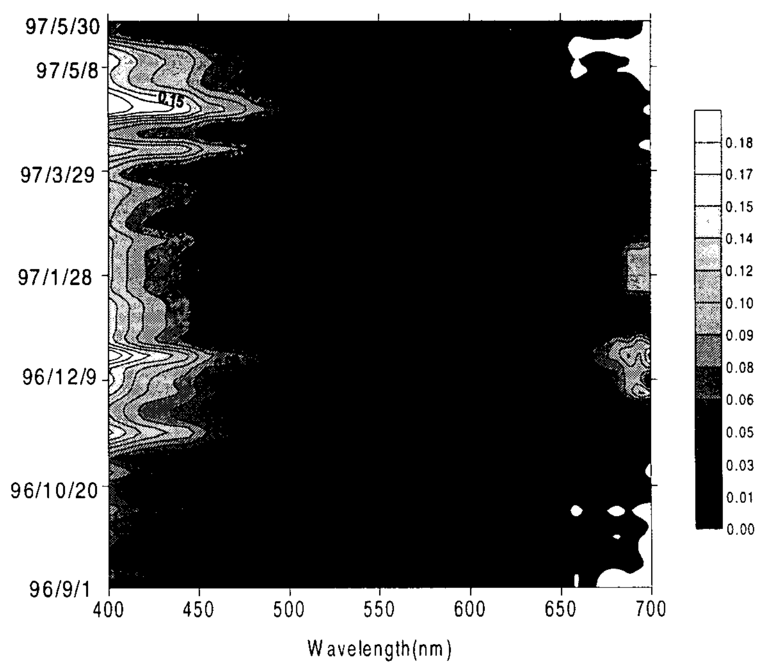


Fig. 10 Seasonal variation of inherent attenuation coefficient spectrum.

**Conclusion**

By using the optical moored buoy data, seasonal variation of attenuation coefficient spectra in Japan sea was extracted from underwater radiance/irradiance spectra. This data set contains still much more useful information for applying future ocean color sensors which provide with super-multi-channel detectors such as GLI and MODES. Our final goal is to generate a global map of the primary production from ocean color imageries. For this purpose, we need more detail analysis to clarify the relationship between phytoplankton and underwater optical field. For example, we have to distinguish the absorption and the back-scattering from the attenuation coefficient, and then to reveal the contributions of phytoplankton and dissolved organic matters in the underwater optical field. And also, we need to analyze the relation between the natural fluorescence and the primary production.

**Acknowledgement**

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