A STUDY ON THE DIFFUSE ATTENUATION COEFFICIENT OF DOWN-WELLING IRRADIANCE AROUND THE YELLOW SEA

Jee-Eun Min[1, 2*], Yu-Hwan Ahn[1], Joo-Hyung Ryu[1] and Kyu-Sung Lee[2]

[1]Satellite Ocean Research Lab., Korea Ocean Research & Development Institute
Ansan P.O. Box 29, SEOUL 425-600, South Korea
jemin@kordi.re.kr
[2]Department of Geoinformatic Engineering, INHA University

ABSTRACT ... The diffuse attenuation coefficient for down-welling irradiance (K_d) is an important parameter for ocean studies including remote sensing applications. For the vast ocean, ocean color remote sensing is the only possible means to get the fine-scale measurements of K_d. To develop a technique of estimating K_d from remotely sensed data, the following underwater optical parameters (absorption coefficient (a), attenuation coefficient (c), scattering coefficient (b), diffuse attenuation coefficient (K_d), etc.) have been studied. For this research we conducted the field campaign around the Yellow Sea at 8~9 June, 2006. We obtained a set of underwater optical parameter data: down-welling irradiance (E_d), up-welling irradiance (E_u) and up-welling radiance (L_u) using TriOS optical sensors and a, c coefficient using Spectral Absorption and Attenuation Meter (AC-S). We then derived K_d values from E_d for each depth.

KEY WORDS: Diffuse attenuation coefficient for down-welling irradiance (K_d), absorption coefficient (a), attenuation coefficient (b), Underwater visibility.

1. INTRODUCTION

Diffuse attenuation coefficient for down-welling irradiance, $K_d(\lambda)$ (where λ is the light wavelength) plays a critical role in the oceanographic studies, providing the basis of representing the optical situation of the sea water column. Several authors studied this parameter in relation to the heat transfer in the upper ocean (Chang and Dickey, 2004; Lewis *et al.*, 1990; Morel and Antoine, 1994; Zaneveld *et al.*, 1981), photosynthesis and other biological processes in the water column (Marra *et al.*, 1995; McClain *et al.*, 1996; Platt *et al.*, 1988; Sathyendranath *et al.*, 1989), and turbidity of oceanic and coastal waters (Jerlov, 1976; Kirk, 1986). The aim of this study is (i) to measure the ocean optical parameters related to Inherent Optical Properties (IOP): a & c coefficient and Apparent Optical Properties (AOP): $K_d(\lambda)$ around the Yellow Sea, and (ii) to analyze correlation for $K_d(\lambda)$ and underwater visibility.

2. METHOD

2.1 Study area

The study area is the Yellow Sea, which is semi-closed sea surrounded by the Korean peninsula and the continent of China. Because many rivers and estuaries are adjacent to this area, abundant nutrient and fresh waters flow into this site. The most striking feature of this area of Yellow Sea is the high level of turbidity .On a detailed scale, our study area is the Saemangeum coastal area, which is situated to the east of the Yellow Sea. In this area, the Saemangeum tidal dyke with 33 km has been constructed and reclamation of shallow estuary is for 41,000ha. Because the tide range of this area is very high, the concentrations of suspended and resuspended sediment particles occur at high level. The water is opaque and colored green compared to blue waters of the open ocean. The waters around this area are typically Case-II water.

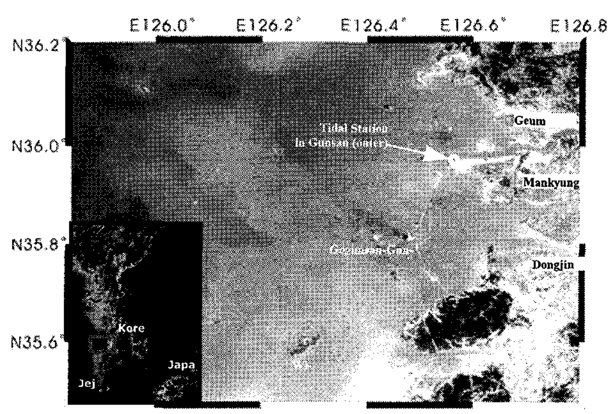

Figure 1. Landsat5 TM (7 May, 2000) color composite image (B321) from the study area of this study, Saemangeum coastal area.

2.2 In situ measurements

Measurements of ocean optical parameters were collected from 19 to 22 September, 2006 on the Saemangeum coastal area in the Yellow Sea. A series of dives were conducted with simultaneous measurements using various optical instruments from approximately 10:00 to 15:00 Local Time (LT) each day. The time of day was planned to maximize the sun's illumination at or near solar noon. Figure 2 shows the location of sampling stations in the study area. The 39 optical data sets have been obtained. To measure the optical properties, we used two optical instruments, namely TriOS, AC-S. TriOS is a UV/VIS spectrometer. Using TriOS we measured the underwater optical parameter data: down-welling irradiance (E_d), up-welling irradiance (E_u) and up-welling radiance (L_u). Spectral Absorption and Attenuation Meter (AC-S) were operated for measurements of spectral absorption and attenuation profiles. In stations of only B group, all measurements have been accomplished. Therefore, in this study we used only B group data for K_d and visibility study.

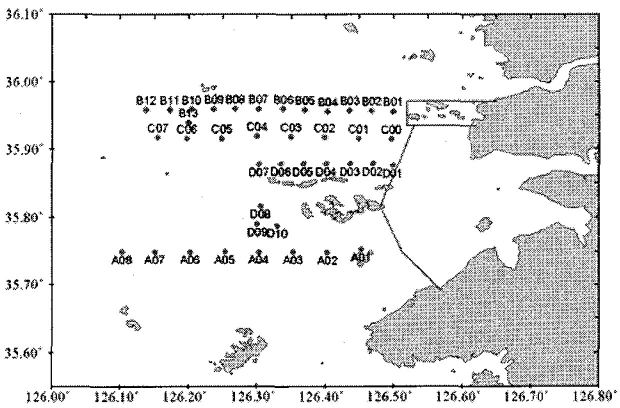

Figure 2. Map of the Saemangeum coastal area showing sampling points/stations during 19 ~ 22 September, 2006.

Table 1. Summary of instruments and measurements of optical properties.

	Instrument	Deployment Method	Measurements	Unit
1	TriOS	Vessel	E_d, L_u, E_u	W/m^2
2	AC-S	Vessel	a, c	1/m
3	Secchi Disk	Vessel	Vertical visibility	m
4	Underwater Camera	Diver	Horizontal visibility	m

The Secchi Disk is the oldest instrument used to observe the clarity/visibility of the water in the vertical coordinate system. It is a simple instrument, yielding immediate information regarding the water clarity and its cost is significantly lower than those of spectral measuring instruments. A 30 cm white disk went down into the water and the depth at which the white disk disappears is the Secchi Depth (SD). Combined with the more expensive instruments the secchi results yield multiple optical properties of the ocean such as c and K. The white disk was also used for horizontal visibility by diver (Figure 3.).

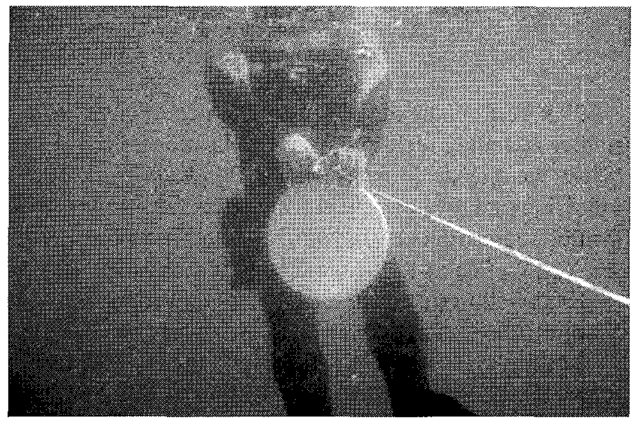
Figure 3. Diver view of a flat white target for horizontal visibility at a depth of 1m.

2.3 Data processing

The decay of radiation in the water is described by an exponential law:

$$E_d(z) = E_d(0^-)e^{-\int_{z_1}^{z_2} dzK_d(z)} \quad (1)$$

Where E_d is the down-welling irradiance, z is depth and K_d is spectral diffuse attenuation coefficient. The 0^- denotes a depth just below the surface of the ocean. From Eq. (1) an expression for the average K_d is obtained assuming that K_d is constant at least in the depth interval $[z_1, z_2]$:

$$K_d = -\frac{1}{(z_2 - z_1)}\ln\left[\frac{E_d(z_2)}{E_d(z_1)}\right] \quad (2)$$

The Apparent Optical Properties (AOP), of these K_d is one, are linked to the Inherent Optical Properties (IOP), which are the absorption and scattering coefficients (a & b) and the volume scattering function which leads to the scattering coefficient.

3. RESULTS

3.1 Diffuse attenuation coefficient for down-welling irradiance (K_d)

The values of K_d were calculated from the E_d profiles. The K_d for the whole layer (0m~20m) for all of the stations are shown in Figure 4. They were all very similar in spectral shape. The lowest K_d value is observed at 580 nm. And the K_d values increase as the wavelength gets shorter than 580 nm. The K_d values also increase as the wavelength gets longer than 580 nm.

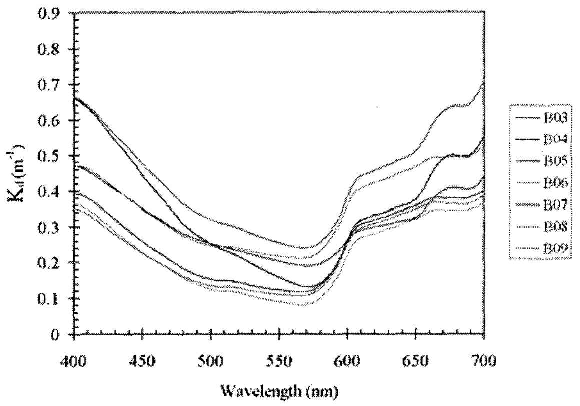

Figure 4. Spectral diffuse attenuation coefficient (K_d) for each stations.

3.2 Absorption (a) & attenuation (c) coefficient

Figure 5 shows the absorption coefficient and attenuation coefficient of the B09 station. The values of both a and c coefficients increase as the wavelength gets shorter. Absorption coefficient at 680 nm increases because of the phytoplankton.

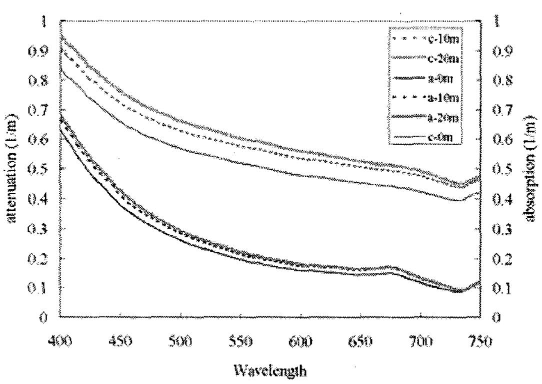

Figure 5. Absorption coefficient (a) and Attenuation coefficient (c) at B09 station.

3.3 Vertical and horizontal visibility

Figure 6. shows the vertical and horizontal visibility at the each station. As getting away from the land, turbidity of water is decreased. Accordingly the visibility is higher like as in Figure 6.

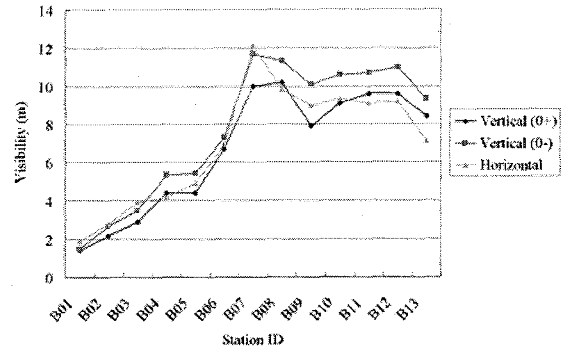

Figure 6. The vertical and horizontal visibility along the transect.

3.4 Relationship between attenuation coefficient and visibility

Attenuation coefficient is inversely proportional to the visibility. The NRL (Naval Research Laboratory) (E. A. Museler, 2003) developed the equations to estimate vertical and horizontal visibility as below.

$$r_{vertical} = \frac{4.0}{c + K_d} \quad (3)$$

$$r_{horizontal} = \frac{4.8}{c} \quad (4)$$

We also analyzed the relationship of two parameters. As a result, we obtained following algorithms; Eq. (5) and (6).

$$r_{vertical} = \frac{6.9}{c + K_d} \quad (3)$$

$$r_{horizontal} = \frac{5.8}{c} \quad (4)$$

where, c and K coefficient are the values at 490 nm spectral band. Our result of $r \times c$ or $r \times (c + K_d)$ is little higher than that of NRL.

4. ACKNOWLEDGEMENTS

This research was supported by the Korean Ocean Research and Development Institute (KORDI). The authors would like to acknowledge the COMS DEVELOPMENT PROJECT (III) (PM39700).

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