# Ship Shadow Effects on Apparent Optical Properties

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## Abstract

Results of an experimental study of ship shadow effects are presented. Spectral upwelling and downwelling irradiance, and upwelling radiance were measured at 2 distances from the ship on an overcast day and sunny day. On the clear sky day it was found that while the apparent properties and derived properties of reflectance showed only negligible affects, the derived diffuse attenuation coefficients varied measurably. On the overcast day the apparent properties varied, with Ed showing the most variation. All of the derived properties on this day exhibited large variations (on the order of 40%) between casts at 0 and 9 meters.

## Introduction

Studies of the ambient light field in the ocean are used to determine downwelling and upwelling irradiance (Ed,Eu)[1] and radiance (Ld,Lu),[2] and the derived quantities of reflectance (R)[3] and diffuse attenuation coefficient (K).[4] These measurements are usually made with submersible radiometers, which are lowered into the ocean from ships. Unfortunately, the presence of the ship, and at some wavelengths the instrument itself,[5] can perturb the light field, thus affecting both the measured apparent optical properties and the derived optical properties. In applications where the measurement of surface and near surface optical properties are required, such as ground truth of satellite data, these perturbations can generate erroneous results.[5] A theoretical study of these effects was performed by Gordon,[5] but no experimental results have previously been reported. Therefore, two field experiments were performed; one on a day with complete overcast and the other on a day with a clear sky, since the extent of ship "shadowing" depends on the sky and lighting conditions. On days with scattered clouds and partial sun the effect would presumably be some intermediate between these two cases.

## Experimental procedure

The measurements were performed from the R/V Capt Hook in March and April (1985) in coastal waters off San Diego, California. A MER-1032 (Biospherics Instruments) radiometer was used which simultaneously measured 8 wavelengths of upwelling radiance and irradiance, and 12 wavelengths of downwelling irradiance. During the study the instrument was deployed from an extendable crane enabling it to be deployed at several distances from the stern of the ship. Three distances (0, 4.5, and 9 m off of the ships stern) were selected to evaluate the variability of the ship shadow effect. The 4.5 m cast was used in conjunction with the 9 m cast to determine the true apparent properties. In most cases the 4.5 m cast was only negligibly different from the 9 m cast and as such indicated that the latter could be used as a true profile of the apparent properties (the only exceptions in this were in Eu and Lu on the overcast day and will be discussed later). Spectral profiles were acquired down to 150 m, with data at certain wavelengths being deleted when the light intensity fell below 5 logs of full scale (indicating signal level of the ambient light was below instrument noise).

Since the casts were taken at slightly different times, the total ambient illumination on the surface varied slightly due to variations in the solar zenith angle. To correct Eu, Ed, and Lu for this, all data taken on a given day are normalized to the same surface illumination using a normalization factor obtained from a surface illumination chart.[6] Since all three casts were acquired within a half hour, no significant variation in K, or R, is expected due to the different solar zenith angles and corresponding changes in radiance distribution.

## Data

### Clear sky day

During the clear sky casts (30 March 1980) the sun was over the stern with solar zenith angles at approximately 36 deg for the 0 m cast zenith angle (data from a solar ephemeris program[7]) and 43 deg for the 9 m cast. Figure 1 shows the log plots at 488 nm of Ed, Eu, and Lu versus depth. For Ed and Lu, both the 0 m and 9 m casts show indistinguishable profiles indicating that there was no measurable effect due to ship shadow. Table 1 gives the spectral ratios of Ed and Lu at 0 and 9 meters at the surface.

Table 1. Clear sky case, depth at which ratio was calculated is in parenthesis.

| Wavelength | Ed(0)/Ed(9) | Eu(0)/Eu(9) | Lu(0)/Lu(9) |
|---|---|---|---|
| 410 | .92(1) | .78(1) | .88(1) |
| 441 | .94(1) | .81(1) | .92(1) |
| 488 | .95(1) | .86(1) | .96(1) |
| 520 | .98(1) | .86(1) | .96(1) |
| 550 | .98(1) | .85(1) | .96(1) |
| 589 | .98(1) | .83(1) | .97(1) |
| 633 | .98(1) | .85(1) | .99(1) |
| 671 | .98(1) | .88(1) | .98(1) |

In Figure 1, the plot of Eu shows that the ship shadow effect, while small, is evident. For 410 nm the effect extends to approximately 9 m, but at other wavelengths the effect occurs only very near the surface. The ratios of Eu(0)/Eu(9) for the surface value (at 1 m) are also shown in Table 1. At 410 nm, the difference between Eu(0)/Eu(9) is 22% and is significant if the value at the surface is desired.

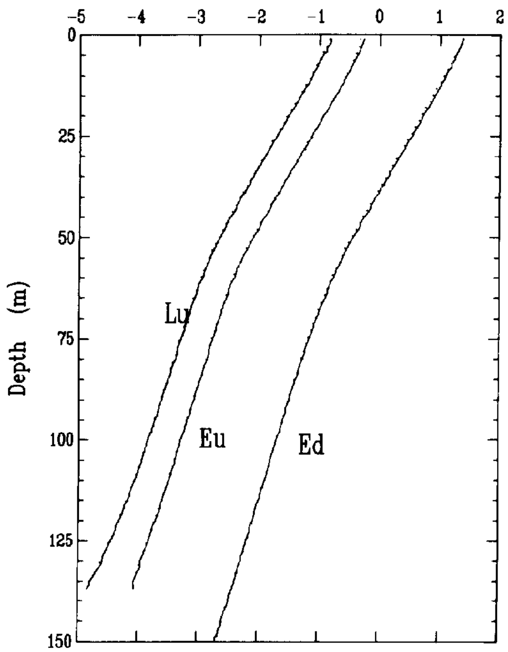


Figure 1. Clear sky case. Log plot of Lu, Eu, and Ed at 488 nm. Lu is in units of $\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$, Eu and Ed are in units of $\mu W\ cm^{-2}\ nm^{-1}$. Solid line is cast at 9 m, dotted line is cast at 0 m.

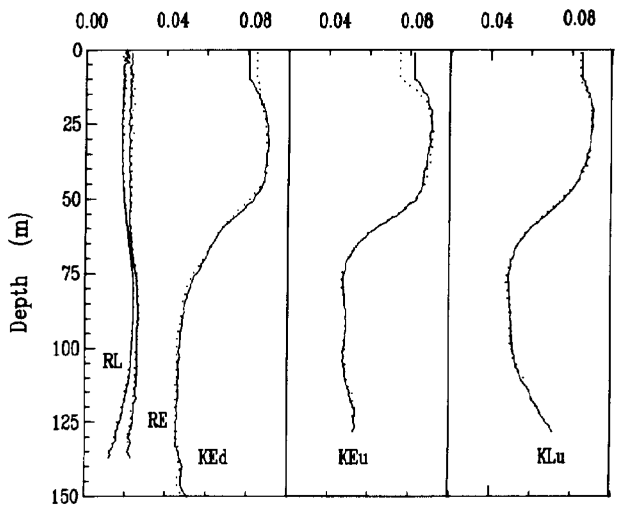


Figure 2. Clear sky case. Plot of derived quantities. Solid line is cast at 9 m, dotted line is cast at 0 m.

The derived quantities [radiance reflectance (RL), irradiance reflectance (RE), downwelling diffuse irradiance attenuation coefficient (KEd), upwelling diffuse irradiance attenuation coefficient (KEu), and upwelling radiance attenuation coefficient (KLu)] as a function of depth are shown in Figure 2. For RL there is very little difference between 0 and 9 m profile. This should be expected since the error in Lu and Ed was small and the radiance reflectance is simply the ratio of Lu/Ed. The irradiance reflectance (RE) profile does show a very small ship shadow effect and also should be expected due to the small, but non-zero, error in Eu (RE = Eu/Ed). The percentage errors in RL and RE are shown in Table 2. The errors in RL are negligible; where as, the errors in RE are large but quickly disappear (at 5 meters it is only 3% for 410 nm).

Table 2. Clear sky case, depth at which the error was calculated is in parenthesis.

| Wavelength | %RL | %RE | %KEd | %KEu | %KLu |
|---|---|---|---|---|---|
| 410 | 3(1) | 16(1) | 3 | 7 | 1 |
| 441 | 2(1) | 15(1) | 3 | 8 | 2 |
| 488 | 2(1) | 13(1) | 5 | 9 | 1 |
| 520 | 1(1) | 14(1) | 6 | 6 | 0 |
| 550 | 1(1) | 14(1) | 6 | 6 | 1 |
| 589 | 1(1) | 16(1) | 5 | 3 | 2 |
| 633 | 0(1) | 14(1) | 4 | 2 | 1 |
| 671 | 0(1) | 11(1) | 3 | 2 | 4 |

The diffuse attenuation coefficients are sensitive to the ship shadow indicating that the slope of the irradiance and radiance curves are influenced more than the absolute light level displacement. This is easily observed in the KEd profile in Figure 2, where the error at 7 m is comparable to the error in KEu even though the Ed profile appeared to be negligibly affected. Below 20 m KEu, KEd, and KLu at 0 and 9 m follow each other implying that shadow effects have disappeared.

Overcast Data

The overcast data was taken on April 4, 1985, when the sky was completely overcast and the solar zenith angles were 68 and 71 degrees for casts at 0 and 9 m, respectively.

Figure 3 shows the log plots at 488 nm of Ed, Eu, and Lu. For Ed the ship shadow effect appears to reach a maximum at approximately 10 meters, then diminishes so that by 25 m the two curves are equivalent. It can be seen in Table 3 that the ship shadow has a large effect in all the wavelengths for Ed.

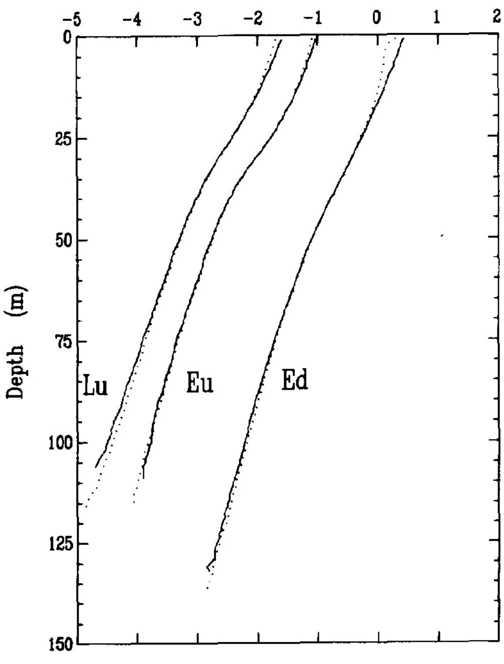


Figure 3. Overcast sky case. Log plot of Lu, Eu, and Ed at 488 nm. Lu is in units of $\mu W\ cm^{-2}\ sr^{-1}\ nm^{-1}$, Eu and Ed are in units of $\mu W\ cm^{-2}\ nm^{-1}$. Solid line is cast at 9 m, dotted line is cast at 0 m.

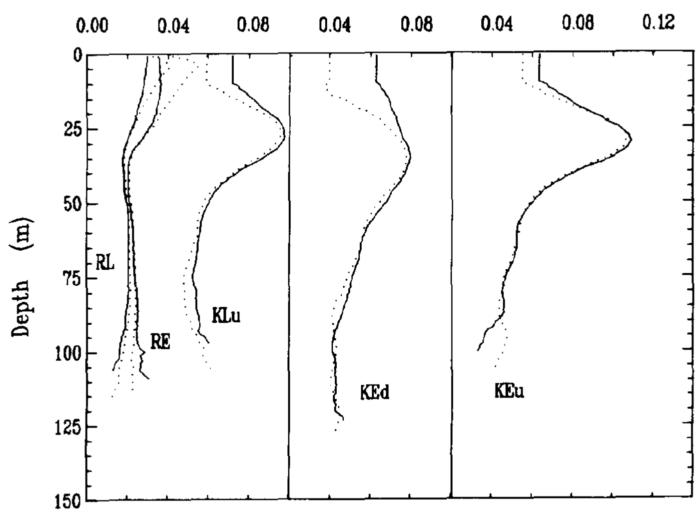


Figure 4. Overcast sky case. Plot of derived quantities. Solid line is cast at 9 m, dotted line is cast at 0 m.

Table 3. Overcast sky case, depth at which ratio was calculated is in parenthesis.

| Wavelength | Ed(0)/Ed(9) | Eu(0)/Eu(9) | Lu(0)/Lu(9) |
|---|---|---|---|
| 410 | .59(4) | .79(1) | .72(1) |
| 441 | .60(4) | .83(1) | .75(1) |
| 488 | .60(4) | .86(1) | .96(1) |
| 520 | .60(4) | .84(1) | .76(1) |
| 550 | .61(4) | .82(1) | .75(1) |
| 589 | .61(4) | .75(1) | .69(1) |
| 633 | .62(4) | .67(1) | .63(1) |
| 671 | .63(4) | .65(1) | .61(1) |

For the profiles of Eu and Lu, in Figure 3, the characteristic hooked shape found for Ed does not occur, although the measurement at 9 meters appears to be changing slope between 0 and 25 m. In these two properties the 4.5 m cast was intermediate, and significantly different from the 0 and 9 m casts. One could speculate that the ship was still affecting the upwelling radiance and irradiance at 9 meters, although measurements at greater distances from the ship were not acquired so this can not be verified. The effect on Eu and Lu is subtle, with changes in the shape indicating a perturbation exists in the measurement. Without comparative data it would be easy to overlook this problem.

RL and RE are shown in Figure 4, the errors in these measurements were as large as 41% (Table 4). Surface values (1 m) were similar, due to compensating errors in Ed and Lu, and Ed and Eu, implying that the surface values would better estimate the true RL or RE than the values at a depth of 5 meters.

Table 4. Overcast sky case, depth at which error measurement is calculated is in parenthesis.

| Wavelength | %RL | %RE | %KEd | %KEu | %KLu |
|---|---|---|---|---|---|
| 410 | 25(5) | 33(4) | 26 | 12 | 16 |
| 441 | 28(5) | 37(4) | 32 | 13 | 17 |
| 488 | 32(5) | 41(4) | 45 | 14 | 19 |
| 520 | 30(5) | 38(4) | 34 | 15 | 21 |
| 550 | 27(5) | 36(4) | 28 | 16 | 21 |
| 589 | 19(5) | 27(4) | 14 | 14 | 19 |
| 633 | 13(5) | 15(4) | 5 | 15 | 15 |
| 671 | 20(5) | 12(4) | 6 | 28 | 42 |

The surface values of K, at 0 and 9 m, show large differences as shown in Figure 4. Table 4 shows that the error in these values are large even in the red wavelengths of 671 and 633 nm. These errors extend to a much greater depth than might be expected, in KEd the effect appears to extend to 35 meters.

## Models for correction

One method of correcting the data is to use a simple geometric model. The model used in this study for the downwelling irradiance assumed no scattering or absorption, and all light is contained in 48 deg half angle cone. This model exhibited the general shape of the Ed case for the cloudy day example as shown in Figure 5, and could be used as a first approximation to correct data. For upwelling radiance and irradiance a simple, realistic model could not be found which could be analytically solved.

A Monte Carlo technique has been used by Gordon,[5] for an instrument deployed off the beam of the ship. This approach is not easily incorporated into an algorithm for correcting data; however, it does give insight into this ship shadow effect.

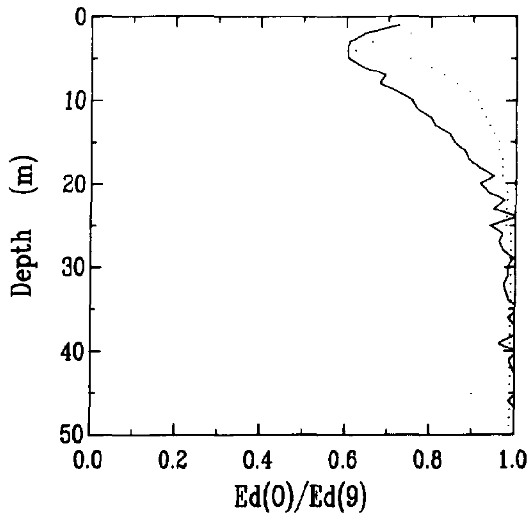


Figure 5. Model and experimental data for overcast day. Points are calculated from model, solid line is Ed(0)/Ed(9).

## Conclusions

This data shows, qualitatively and quantitatively, how the ship shadow can affect apparent and derived optical properties. The results have shown that on sunny days, with proper orientation for the ship to minimize direct shadowing, negligible errors occur. On cloudy days these examples can be used to recognize ship shadow effects and make first order corrections of data. This experiment has shown that the effect varies with lighting conditions; different water types and hull shapes should also change the ship shadow, therefore, extending the results of this test to other cases must be done with care. More extensive Monte Carlo modeling studies would be useful in determining how different water types effect the ship shadow. We are currently working on this and on constructing an Electro-Optical camera system to measure the radiance distribution. With this radiance distribution data we hope to devise a more realistic model of the ship shadow.

## Acknowledgements

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