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Upwelling spectral radiances from the water surface and *in situ* inherent optical properties are measured concurrently at the same locations. Values of spectral radiance reflectance coefficients are derived from *in situ* data and compared with those obtained from spectral radiance data. An algorithm for estimating reflectance coefficients based on attenuation and absorption data is proposed and evaluated. This algorithm is based on the theoretically derived equations and the experimentally obtained regressions that connect scattering and backscattering coefficients. Overall comparison of derived and measured radiance coefficients shows that this algorithm is suitable for processing ground truth data for the purposes of calibration remote and *in situ* optical measurements.

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Remote Sensing -- A Scientific Vision for Sustainable Development

Retrieval of Remote Radiance Reflection Coefficients of Coastal Waters from the Inherent Optical Properties

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Abstract — Upwelling spectral radiances from the water surface and *in situ* inherent optical properties are measured concurrently at the same locations. Values of spectral radiance reflectance coefficients are derived from *in situ* data and compared with those obtained from spectral radiance data. An algorithm for estimating reflectance coefficients based on attenuation and absorption data is proposed and evaluated. This algorithm is based on the theoretically derived equations and the experimentally obtained regressions that connect scattering and backscattering coefficients. Overall comparison of derived and measured radiance coefficients shows that this algorithm is suitable for processing ground truth data for the purposes of calibration remote and *in situ* optical measurements.

INTRODUCTION

The results of the spectral measurements of radiance reflectance coefficient are compared with the results of the retrieval of these values from *in situ* measuments of inherent optical properties. These data are obtained simultaneously during the ground truth experiment near the West Florida coast in August 1994 (see Fig. 1). Upwelling spectral radiances from the water surface and *in situ* inherent optical properties are measured concurrently at the same locations. Values of spectral radiance reflectance coefficients are derived from *in situ* data and compared with those obtained from spectral radiance data. A model for estimating reflectance coefficients based on attenuation and absorption data is proposed and evaluated.

The measurement systems are: (a) spectral radiometer, with sensor bandwidth of 350-1000 nm and a one-degree acceptance angle (Analytical Spectral Devices, Inc. model FieldSpec™ VNIR); (b) nine-band beam absorption and attenuation meter (WETLabs, Inc. model A/C-9).

Data are collected at nine stations that range in depth from 2 meters to 23 meters. The spectral radiometer reflectance measurements are made at 30° from nadir and 180° azimuth from the sun. The examples of relative measurements are shown in Fig. 2. The vertical profiles of inherent optical properties are collected with the submersible A/C-9 beam transmissometer. The absorption and attenuation coefficients (see Figs. 3) are collected at nine stations transecting perpendicularly from the shoreline.

APPROACH

The experimental values of radiance reflection coefficient ρ_{mes} were calculated from three relative measurements of the sea N_{sea}, sky N_{sky}, and gray reference reflector N_{ref}:

$$\rho_{mes} = \left[A_{ref}\left(N_{sea} - R_F N_{sky}\right)\right] / \left(\pi N_{ref}\right), \tag{1}$$

here A_{ref} is the reference albedo, and R_F is the Fresnel reflection coefficient of skylight [1]. Examples of measured radiance coefficients ρ_{mes} are shown in Fig. 4.

The radiance reflection coefficients ρ_{res} derived from the a and b profiles are calculated according to the equation:

$$\rho_{res} = T_d T_u R = R\left(1 - R_F\right)^2 / n_w^2, \quad R = R_1, \tag{2}$$

here T_d and T_u are, respectively, downward and upward transmission coefficients of the sea surface, n_w is the water refractive index, and R is the diffuse reflectance of the water mass including effects of reflection from the bottom. The diffuse reflectance of a stratified n-layered shallow sea was computed using the following iteration formula:

$$R_n = \frac{R_n^\infty(1 - R_n^0 R_{n+1}) + (R_{n+1} - R_n^\infty)\exp\left[-v_n(z_{n+1} - z_n)\right]}{(1 - R_n^0 R_{n+1}) + R_n^0(R_{n+1} - R_n^\infty)\left[-v_n(z_{n+1} - z_n)\right]}, \tag{3}$$

$$R_{n+1} = A_B, \quad z_{n+1} = z_B. \tag{3a}$$

Here A_B is the bottom albedo and z_B is the sea depth. All other parameters are inherent optical properties of the n-th layer calculated through the absorption and scattering profiles (see Figs. 3) measured during the experiment.

$$v_n = 2 a_n \frac{2(x_n - R_n^\infty) - \bar{\mu}_n x_n}{(1 - x_n) R_n^\infty} \tag{4}$$

$$R_n^\infty = \left(\frac{1 - \bar{\mu}_n}{1 + \bar{\mu}_n}\right)^2, \qquad R_n^0 = \frac{2 - \bar{\mu}_n}{2 - \bar{\mu}_n} R_n^\infty, \tag{5}$$

$$\begin{aligned}\bar{\mu}_n = \eta_n (2.6178398 \ &+ \eta_n (-4.6024180 + \\ &+ \eta_n (9.0040600 + \eta_n (-14.59994 + \\ &+ \eta_n (14.83909 + \eta_n (-8.117954 + \\ &+ 1.8593222\, \eta_n)))))), \quad \eta_n = \sqrt{1 - \omega_n^0}.\end{aligned} \tag{6}$$

$$\omega_n^0 = \frac{a_n}{a_n + b_n}, \quad x_n = \frac{(1 - \bar{\mu}_n^2)^2}{1 + \bar{\mu}_n^2 (4 - \bar{\mu}_n^2)}, \quad b_n^B = \frac{x_n a_n}{1 - x_n} \tag{7}$$

Equations (3)-(5), and (7) are based on the theory presented in Refs. [2]-[3]. The empirical Eqn. (6) is derived by the author from the experimental and *in situ* results published by Timofeyeva [4]. All values in Eqns. (4)-(7) with the subscript (n) are referred to the n-th layer. They are as follows: a_n is the absorption coefficient, x_n is the Gordon's parameter, b_n is the scattering coefficient, $\bar{\mu}_n$ is an average cosine, ω_n^0 is the single-scattering albedo, and b_n^B is the backscattering coefficient.

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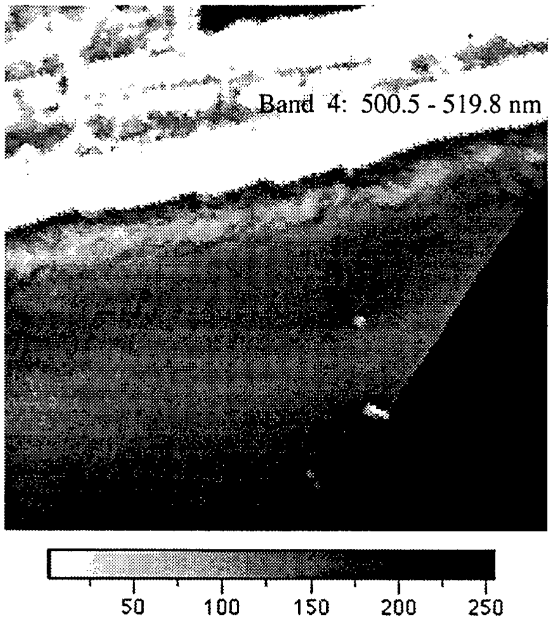

Fig. 1. The image of the investigation area obtained from an aircraft. The center of the optical channel is located near 510 nm. The white elongated spot near the right black border of the sea image is a research vessel.

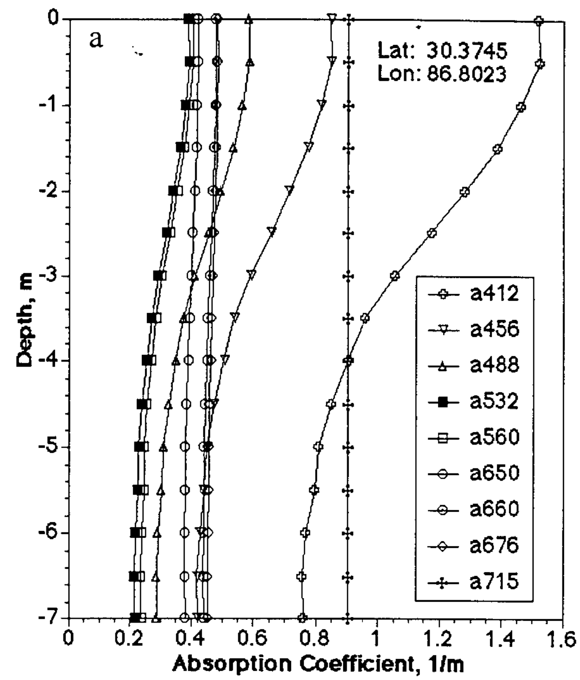

Fig. 3a. Experimental values of the absorption coefficient measured August 8, 1994, in the area shown in Fig. 1.

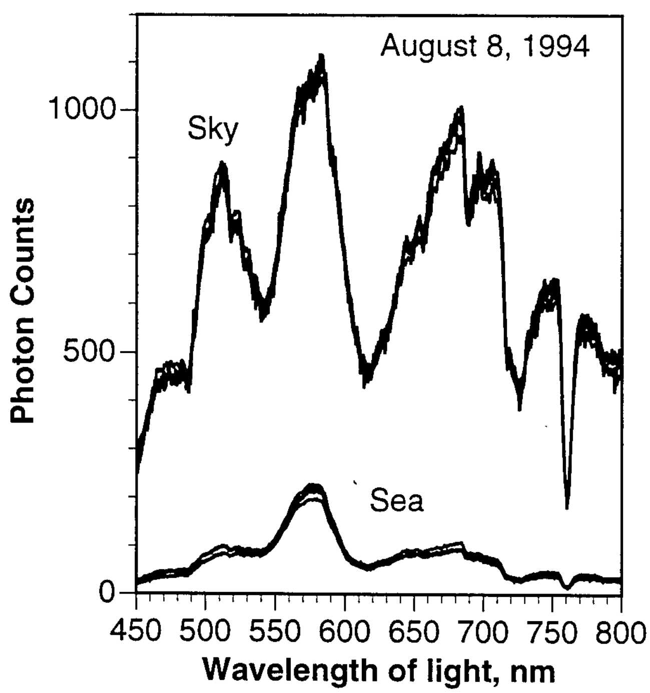

Fig. 2. Examples of the sea and the sky spectral radiances (in relative units) measured from the vessel in the area shown in Fig. 1.

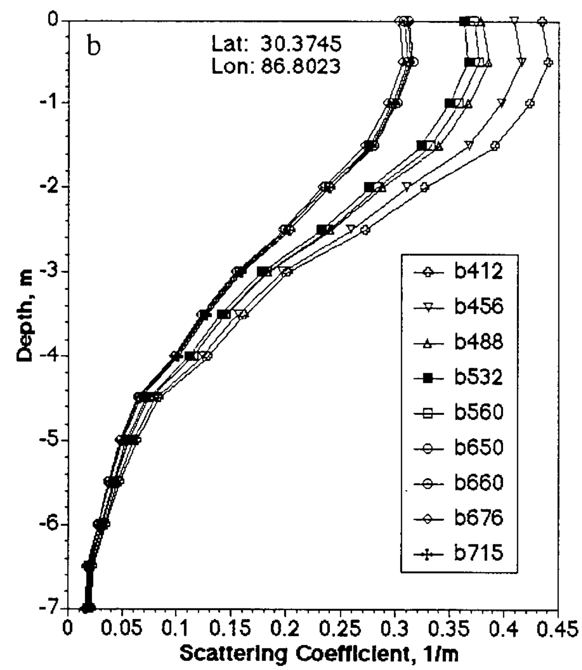

Fig. 3b. Experimental values of the scattering coefficient measured August 8, 1994, in the area shown in Fig. 1.

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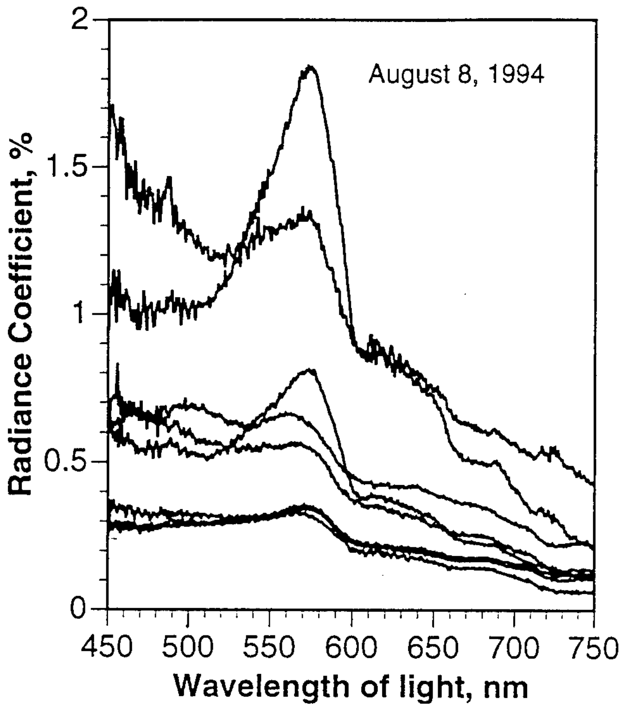

Fig. 4. Examples of the restored with Eqn. (1) radiance coefficients ρ_{exp} for different shallow water stations near the West Florida coast.

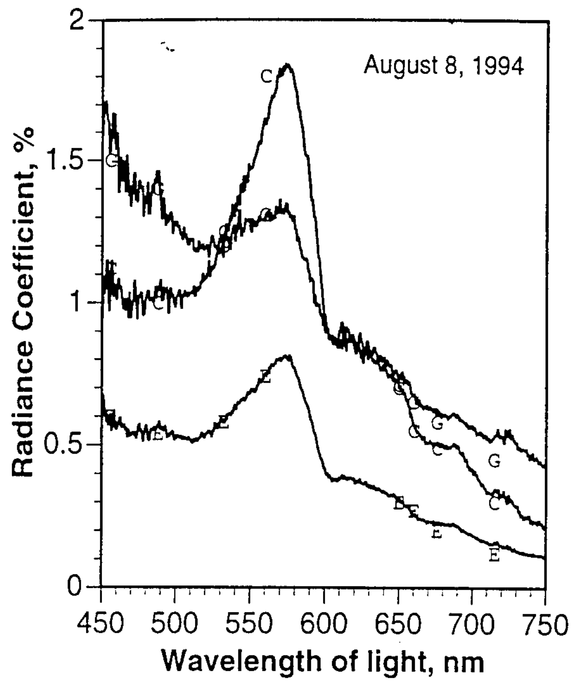

Fig. 5. Experimental (lines) and restored (symbols) values of radiance reflection coefficient for August 8, 1994, West Florida coastal waters.

Figure 5 shows the comparison of the measured and restored radiance reflection coefficients. The overall error of restoration of the spectral radiance reflection coefficients with the algorithm presented above does not exceed 20% for our experiment.

CONCLUSION

The results of the spectral measurements of the radiance reflectance coefficient measured remotely from a small ship are compared with the results of the retrieval of this values through the *in situ* measured profiles of absorption and scattering coefficients obtained simultaneously during the ground truth experiment near the West Florida coast.

The presented algorithm for retrieval of the radiance coefficient using observed depth profiles of absorption and scattering coefficients is stable. The derived values, in the worst cases, have error less then 20%. The overall comparison of the derived and measured radiance coefficients shows that this algorithm is suitable for the calibration remote data using *in situ* observations.

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REFERENCES

[1] Jerlov, N. G., *Marine Optics*, Elsevier, Amsterdam-Oxford-New York, pp. 247, 1976.

[2] V. I. Haltrin (a. k. a. В. И. Халтурин), "The Self-Consistent Two-Stream Approximation in Radiative Transfer Theory for the Media with Anisotropic Scattering," *Izv., Atmos. Ocean Physics*, Vol. 21, pp. 452-457, 1985.

[3] V. I. Haltrin, "Algorithm for Computing Apparent Optical Properties of Shallow Waters under Arbitrary Surface Illumination," in: *Proceedings of the Third International Airborne Remote Sensing Conference and Exhibition*, 7-10 July 1997, Copenhagen, Denmark.

[4] V. A. Timofeyeva, "Optical characteristics of turbid media of the seawater type," *Izv. Atmos. Ocean Physics*, Vol. 7(12), pp. 1326-1329 (863-865), 1971.

[5] V. I. Haltrin, W. E. McBride III, and T. E. Bowers, "Predicting subsurface optical properties," in: *Ocean Technology at Stennis Space Center, Proceedings of the Gulf Coast Section Marine Technological Society, 23-24 April 1997*, Publ. by Naval Oceanographic Office, pp. 17-20, Stennis Space Center, MS, 1997.