CHAPTER 10

OPTICAL PROPERTIES AT EXTREME DEPTHS

10.0 Introduction

In this chapter we examine some theoretical and experimental evidence for possible regular behavior of apparent optical properties at deep and shallow depths in natural bodies of water. These extreme depths in a natural hydrosol are the settings of interesting and complex radiometric interactions of light from the sky with the body of the medium. The observed interactions at these depths are exaggerated either because of the extreme proximity of the air-water boundary or because of its extreme remoteness and thus present to both theoretical and experimental workers a challenging puzzle to unravel and bring conceptual order to the understanding of the light field observations at these depths. In the attempt to understand the radiometric phenomena at extreme detphs, we shall be led to supplement the collection of laws governing the optical properties derived in Chapter 9 (which hold for all depths in a natural hydrosol). Furthermore, by concentrating on the extreme depths in the present chapter, we can extract correspondingly more detailed behavior of the observable K-functions of both the radiance and irradiance fields. Our investigations are based on the general equation of transfer and on the exact two-flow equations for irradiance of Chapter 8; in particular we shall make extensive use of the accurate two-D model for irradiance fields developed in Chapter 8.

We shall begin with the study of irradiance fields at shallow depths in media with calm surfaces, our primary aim being to discern from both theoretical and experimental clues, the precise nature of the depth-behavior of the upward and downward irradiance fields $H(z,\pm)$ at these depths. By examining these fields via their K-functions $K(z,\pm)$ we shall, as it were, be examining them under a powerful magnifying glass by means of which every tendency of decay or growth of $H(z,\pm)$ is limned in bold relief against a conceptual background of algebraic signs and magnitudes of derivatives.

The second half of the chapter is devoted to the study of the natural light fields at great optical depths as they occur in oceans, harbors, and deep lakes. At remote distances from the generally disturbing air-water boundary of the medium, the radiance distributions eventually attain a smooth, characteristic shape independent of the external lighting conditions and dependent only on the inherent optical properties α , σ of the medium. The problem of the nature of the light field at great depths in natural waters has been completely solved only recently. As a result of having a theoretical basis for the existence of the regular behavior of the light field at great depths (for most practical purposes, beyond 10-20 attenuation lengths), we can justify certain simplifications of the models for light fields below such depth intervals. In particular, in such regions the classical canonical form of the equation of transfer (Chapter 4) for radiance, and the two-D model for irradiance (Chapter 8) can be demonstrated to serve as accurate tools with which to quantitatively predict the magnitudes of the natural light fields.

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10.1 On the Structure of the Light Field at Shallow Depths: Introductory Discussion

In this section experimental determinations of the upwelling and downwelling irradiances are studied with the purpose of explaining certain observed regular nonlinear trends in the semilog plots of these irradiances, principally at shallow depths in media with flat calm surfaces. We shall develop a mathematical model from the general equation of transfer which describes these irradiances in great detail over the shallow-depth range. The model explains the observed phenomena in terms of the inherent optical properties of the medium and its external lighting conditions. On the basis of experimental evidence, cited below, and on the basis of supporting theory, the following hypothesis about light fields in all homogeneous natural hydrosols is proposed: (a) The ratio of the upwelling irradiance to the downwelling irradiance, i.e., the observable reflectance function $R(z,-)$, is invariably monotonic increasing or decreasing at shallow depths with increasing depth (depending on the medium) and approaches a limit which is independent of the external lighting conditions and which depends only on the inherent optical properties of the medium. (b) The logarithmic derivatives, i.e., the K-functions $K(z,\pm)$, of the upwelling and downwelling irradiance at shallow depths are monotonic increasing or decreasing with increasing depth (depending on the medium) and approach a common limit which is independent of the external lighting conditions and which depends only on the inherent optical properties of the medium. In this way we arrive at a fairly detailed understanding of the light field at extreme depths (shallow and deep) in all homogeneous natural hydrosols.

To set the stage for the general reader, the following observations on the empirical roles of the K and R functions will be helpful. For many practical purposes in applied hydrologic optics the downwelling irradiance $H(z,-)$ at a depth z in a natural hydrosol can be represented by the following simple formula

$$H(z,-) = H(0,-)e^{-Kz} \quad , \qquad (1)$$

where K is a fixed number which characterizes the overall flux transmitting properties of the hydrosol. A similar formula may be used to determine the upwelling irradiance $H(z,+)$ at any depth z :