CHAPTER 8

MODELS FOR IRRADIANCE FIELDS

8.0 Introduction

In this chapter we shall develop some simple models of light fields in natural optical media, models which have been found to be most useful in the study of radiative transfer in the seas and the atmosphere. These models are built around the concept of irradiance and derive their simplicity and utility directly from the simplicity and utility of irradiance itself. For irradiance is the concept which describes radiant flux per unit area on a surface, and as such utilizes a single number rather than an infinite set of numbers as in the case of the radiance distribution studied throughout Chapter 7. The introduction of irradiance fields into the study of natural light fields is also encouraged by the following convenient geometric structure of the light fields found in the atmosphere, the sea, lakes and other natural hydrosols: over relatively great distances in all directions within horizontal planes in the sea or air, the natural light fields are often found to vary essentially very little, so that an irradiance value at one point of a plane matches that at other quite remote points on the plane; the points being 'remote' in the sense that they are separated by distances vast compared with the attenuation lengths of the media. This latter feature is especially noted in the seas and other laterally extensive natural hydrosols. Because of this gentle almost imperceptible variation over such planes, the radiometric field over these planes may be characterized by the single irradiance magnitude common to all points of a given plane. As a consequence the description of the flow of radiant energy down into the depths of the sea or into the atmosphere can often be reduced to the description of an irradiance flow along any one of the straight lines normal to the family of horizontal planes comprising that portion of the air or sea of interest. In short, the appropriate introduction of an irradiance field into a plane parallel medium reduces the description of the radiative transfer problem within that medium to a one-dimensional problem.

One of the more fascinating features of irradiance fields in plane-parallel media, especially for the theoretically inclined investigator, is the fundamental similarity between the basic equations for irradiance fields and those for the radiance distributions as studied, e.g., in Chapter 7. The similarity is a thorough-going one which may, indeed, be used as a heuristic guide in pursuing either subject matter, using the other as a base. In this connection, it may be noted that the original forms of the invariant imbedding relations and internal source relations studied in Chapter 7 were tentatively found in the irradiance context by means of informal scratch pad calculations; the simplicity of their derivation and resultant forms in that context encouraged the rigorous search for the associated full fledged operator equations for radiance sprinkled throughout that chapter.

We shall be guided in our discussions in the initial sections of this chapter (8.1, 8.2) and once again in Section 8.7 by the close conceptual connections between the functional equations for irradiance and radiance fields. In this way we can effect a smooth transition from the general formulations of Chapter 7 to the simpler settings of this chapter and at the same time gain some insight into the unity of the theory engendered by the invariance concepts. However, for the main sections of the chapter (8.3-8.6) the discussions will for the most part dwell on specific models which have been tried and found useful in the daily tasks of obtaining numerical estimates and rule-of-thumb algebraic approximations to the magnitudes of light fields, and the properties of their associated optical media.

Throughout this chapter we shall work with an arbitrary plane-parallel medium $X(a,b)$ and adopt the reference frame for $X(a,b)$, as defined in Section 2.4. Furthermore the steady state irradiances $H(z,\pm)$ defined in Section 2.4, along with their attendant radiometric concepts, will be adopted without further explanation. The medium $X(a,b)$ will be assumed free of internal sources unless specifically noted otherwise, and arbitrarily stratified with a stratified light field, so that both radiometric and optical properties depend only on depth z within $X(a,b)$, $a \le z \le b$. Arbitrary sources are incident on the upper and lower boundaries of $X(a,b)$. (In real media, however, it is customary in practice to have no sources incident on the lower boundary.) The explicit retention of a source on the lower boundary will have the effect of keeping the resultant theoretical imbeding relations in their full symmetric form.

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8.1 Invariant Imbedding Relation for Irradiance Fields

Our point of departure for the present discussion is the set of principles of invariance (7), (8) of Section 3.7. We recall that these statements were deduced from an application of the interaction principle to an arbitrary subslab $X(x,z)$ of a plane parallel medium of the type $X(a,b)$, schematically depicted in Fig. 8.1. The results may be written:

$$\text{I.} \quad H(y,+) = H(z,+)\,T(z,y) + H(y,-)\,R(y,z) \tag{1}$$

$$\text{II.} \quad H(y,-) = H(x,-)\,T(x,y) + H(y,+)\,R(y,x) \tag{2}$$