9.1 Basic Definitions for Optical Properties

The optical properties of a natural optical medium, such as the sea, or a lake, or a portion of the atmosphere, may be broadly grouped into two classes: those that are inherent optical properties and those that are apparent optical properties. In simple terms, an inherent optical property of a medium is independent of the various possible lighting conditions that may occur in the medium, whereas an apparent optical property varies with the lighting conditions but usually in such a manner that its other regular properties justify its assignation of the title "optical property." More precisely, and in the terms we have used in the closing remarks of Sec. 3.10, we can make the following

Definition 1: An optical property P of a subset S of optical medium X (P in the form of a number, function, or operator) such that P is independent of the incident radiance distributions on S will be called an inherent optical property of S ; otherwise, P is an apparent optical property of S .

Here are some examples of inherent optical properties: the volume attenuation function a, as defined in Sec. 3.11; and the beam transmittance function T_r as defined in Sec. 3.10. The independence of these properties from the shape and magnitude of ambient radiance distributions is evident at once from an inspection of their definitions. For example, in the case of T_r , it is seen from (2) and (3) of Sec. 3.10 that T_r is independent of the radiance distributions occurring along the path r(x,C) In an optical medium X. As another example of an inherent optical property of a medium, we have the volume scattering function a. This important concept is developed in three distinct ways throughout the present work so as to establish it to the satisfaction of both theoretical and practical workers in the field. Its empirical definition, the one used in real light fields to obtain the actual values a (x;E';E), is presented in Sec. 13.6.. The independence of a from the directional structure of the radiance distributions is at once evident from a study of that definition. The definition of a as the kernel of the path function operator, as given in Example 1 of Sec. 3.17, is precisely what the theoretical worker can best use, and this definition makes manifest the independence of a (x;~';~) from radiance distributions N (x, E) at x . Finally, an approach to the definition of a that lies half way between the preceding two approaches and which shares the virtues of each, is given in (5) of Sec. 3.14.

Still other examples of inherent optical properties are the volume total scattering function s and the volume absorption function a defined in (3) and (4) of Sec. 4.2. These are seen to be independent of the ambient radiance distributions because they are derived directly from the inherent optical properties a and a without the use of any further radiometric concepts.

The examples of inherent optical properties just given are all instances of a type of optical property which is associated with points x of the medium X, or very small

volumes of X. It is useful to occasionally emphasize this fact and we provide the basis for the appropriate terminology via:

Definition 2: An optical property of an optical medium X which as t e points of X or the points of some subset S of X in its domain of definition, is a local optical property; an optical property of X which has x itself or subsets S of X in its domain of definition, is a global optical property of Some examples of global optical properties are the R and T operators (or their kernels) for slabs X (x, z) of a plane-parallel medium X(a,b), as given in Sec. 3.6. Here the subsets x(x, z) of x(a,b) comprise the domain of the operators R and T. The R and T factors given in Example 1 of Sec. 3.7 are also examples of global optical properties of X(a,b). The R and T operators are at the same time inherent optical properties of their associated plane-parallel media (e.g., R(x,z) is an inherent global optical property of X (x, z)) . On the other hand the R and T factors of Example- 1 of Sec. 3.7 are apparent 'global optical properties because they vary with the directional structure of the incident radiance distributions on their respective slabs. Observe how the shape of the incident radiance distributions in that example were initially fixed and held fixed throughout the medium, and recall the representations of these R and T factors as given by the two-D theory of irradiance models in Chapter 8.

Examples of local apparent optical properties are found in the two-D irradiance models. For example,a (z , ±) , f (z, ±) , s (z, ±) , a (z,±) (in (6)-(8) and (13) and (14) of' Sec. 8.3) are local apparent optical properties because they incorporate the distribution functions D(z,±) or employ radiance distributions in a way that clearly makes them dependent on the angular structure of the radiance distributions. Thefunctions 'T (z,±) and p (z,±) - in (3) and (4) of Sec. 8.2 are also local apparent optical properties.

The operators p(y) and.¯r(y) (or their anisotropic generalizations $p_{\pm}(y)$,$T_{+}(y)$) in (3) and (4) of Sec. 7.1 are examples of local inherent optical properties which are distinct from a and a but which are just as capable as a and o in developing radiative transfer theory. On the other hand the standard scattering function S (X ; - , - ; • , -) as given in (1) of Sec. 3.8 is an inherent global optical property which can be used to reconstruct radiative transfer theory from scratch, as is briefly indicated in that section and as is shown ' in detail in Sec. 126 of Ref. [251]. These observations bring out the idea of an optical property or a set of optical properties (most likely inherent) which can be used to construct all of radiative transfer theory. Since the equation of transfer is a central working tool of the theory, we shall use it as a criterion for deciding whether a set of optical properties is fundamental, and since a and a form the optical heart of the equation, we shall agree to the following:

Definition 3: A set Q of optical properties is said to be fundamental for a medium X with constant index of refraction n if, via p , along with the laws of geometrical

radiometry and the interaction principle, it is possible to derive the equation of transfer for X ; or equivalently, if via 60 and the same auxiliary means, the volume attenuation function a and the volume scattering function a in X can be derived.

Some examples of fundamental sets of local optical properties are (a,6) , (a,p) where p is the phase function (see (3) of Sec. 7.12). Furthermore, (a, a) , (p+ (y) , T+ (y)) are fundamental sets of local optical properties. All of these are inherent optical properties.

Some examples of fundamental sets of global optical properties are the opera tor pairs (R,T) for slabs X (x, z) in a plane-parallel medium

X (a, b) , or the operator pairs (Q J) for one-parameter subsets X(x, z) of one-parameter optical media X(a,b), and finally the operator pair (R,T) in (5) and (12) of Sec. 3.17. All of these are inherent optical properties. In the slab examples, there are to be two pairs of R and T operators or two pairs of Q and 7' operators associated with every subs lab X (x, z) of X (a, b) . Pairs of optical properties such as (a,s), (a, s) , are not fundamental since ° s , being an integral of a over _R has lost too much information in being formed, so that it is generally impossible, except in the simplest of cases ,to retrace the steps to Q. The trivial exceptions occur when, e.g., a is isotropic, or the medium is purely absorbing so that $_a$ = ©.

Looking back over the preceding definitions and examples we see that the means of telling one type of optical property from another has been made quite clear. There re mains, however, the task of classifying the origins of the various optical properties, and of clarifying what is meant by the basic terms "optical property" and "optical medium" hitherto used only with their-intuitive meanings. For completeness, these definitions are now given.

Definition 4 (for General Radiative Transfer) : An optical medium is an ordered septuple (X,N)n,a,6,a,Ne) where X is a subset of euclidean Euclidean space, N a radiance function on X x 'a, n the index of refraction function, a, a are respectively the volume attenuation and scattering functions, o the volume transpectral scattering function, and N_e the true emission radiance function. All these functions are nonnegative, real-valued functions.

The only terms used above that are not formally defined in this work are 6 and N_e (see discussion following (2) of Sec. 3.15). These terms are relatively subordinate as far as magnitude of effects is concerned as they occur in geophysical optics and particularly in hydrologic optics, and for that reason are omitted from the present considerations. However, they generally are to be treated on par with the remaining concepts, and the delineation of their salient properties may be found in Sec. 19 of Ref. [251]. In view of this, for all practical purposes of hydrologic and atmospheric optics, one may adopt as the definition of an optical medium, the following:

Definition 5 (for Geophysical Optics) : An optical medium is an ordered quintuple (X,N,n,a,a), where X,N,n,a, and a are as given in the general definition 4 above. For

brevity, the optical medium, i.e., the quintuple, is usually referred to simply as t' y ", Finally, we make clear the meaning of the term "optical property"' as it is used in radiative transfer theory, by means of the following:

Definition,--6_: An optical property of an optical medium y is any interaction operator s , including its components sib..* if any, arising from the use of the interaction principle in X .

Several comments can be made on the preceding definition which will help tie together the ideas of this and the following sections. First, we deduce from definitions 1 and 6 that the inherent optical properties are precisely those which arise when the incident radiometric quantities used in the interaction principle are radiance distributions; all other types of incident radiometric quantities by definition give rise to apparent optical properties. Second, when S in the interaction principle of Chapter 3 is a one, two, or three dimensional subset of X , then the associated optical property is a global property. If S is a subset of

X consisting of one point (a zero dimensional subset of y) then the associated property is a local property. Finally, it is helpful to distinguish between optical properties which are associated with diffuse or n-ary (in other words decomposed) radiometric functions and undecomposed functions [re: (19) through (22) of Sec. 5.1 and Sec. 8.4). The undecomposed radiometric functions are those that are *directly observed* in nature with the standard radiant flux meters and their variant instrumental forms; and to emphasize this feature, we shall in the present work also refer to such radiometric quantities and their associated optical properties as *direct 2y observable*.