

PREFACE

The central problem addressed in this volume is the prediction of the reflected radiance distribution from a random sea surface, and the transmitted radiance distribution entering the body of the sea below the random surface. The main results are presented in equations (18) and (44) of Sec. 12.11. These equations describe the predicted radiance in terms of the wind-generated statistical parameters of the sea surface, such as mean square wave height, wave slope, and sky radiance distribution. With possible future oceanographic and meteorologic applications of this theory in mind, I have appended in Sec. 12.14 a hierarchy of approximate versions of the exact theory ranging from the exact time-averaged radiance theory down to the simple model of contrast transmittance of a random sea surface which I solved many years ago (Preface, Vol. I) as one of my first research problems in the subject of hydrologic optics.

The inverse problem to that considered in this volume is of considerable interest to the ongoing research problem of global weather and climate prediction: given the observed glitter pattern on the oceans and seas of the earth (as observed by satellite), it is required to find the surface wind speeds over those hydrosols. The theory developed below presents all the elements needed to solve this problem via pattern recognition methods: We can now compute reflected radiance distributions under a wide variety of wind speed, fetch and duration conditions, and thereby can select the appropriate wind speed for the observed glitter pattern. Corrections for intervening path radiance can be made so that the inherent ocean surface radiance can be estimated. Knowledge of the wind speed, duration, and fetch are thus forthcoming and in turn help in the determination of evaporation rates and advective ocean currents, both important parts of the global weather prediction problem.

Another application of the present theory is to the heating rate of the oceans and seas by transmitted visible radiant energy past the random air-water surface into the body of the hydrosol where it undergoes absorption and hence transformation into thermal energy. Knowledge of the optical state of the sea, given by the solution of the inverse problem above, permits a local estimate (via (44) of Sec. 12.11) of the average irradiance transmittance of sun and sky light into the sea with proper allowance for wave slope and wave height effects (which are critical in sub-polar regions), so that thermal conversion estimates can be made. For the latter estimates we must in turn have reliable ways of documenting the oceanic volume absorption function over the visible spectrum. Several ways of achieving these measurements are given in Chapter 13, which closes the present work. Such knowledge of the thermal component of the

energy budget in the sea, along with an understanding of the vertical and horizontal mixing processes in the upper layer of the ocean will be instrumental in predicting short period climatic fluctuations.

The observations above indicate the important role of radiative transfer calculations in the problem of weather and climate prediction. The theory presented in the six volumes of this work on hydrologic optics, while ostensibly directed toward oceanographic matters, also applies to meteorologic problems of radiative transfer. In particular the work applies to the difficult problem of predicting radiative transfer in the visible wavelengths (prior to absorption) through vertically and horizontally structured clouds, haze, and various aerosols. The solution procedures of Vol. IV, in particular those of Sec. 7.11, should help cast some light on this problem which appears to be of central concern in both short- and long-range weather prediction efforts.^{2,3}

In the future, satellites will play an important role as observation platforms from which we can obtain instantaneous optical surveys of the physical properties of the lower atmosphere and upper ocean dynamics needed in furthering our understanding of the combined atmosphere-ocean prediction problem. Because any part of the ocean is masked over the visible spectrum approximately fifty percent of the time by clouds, it is important that we endow our electromagnetic probes with the ability to scan over longer electromagnetic wavelengths. Infra red spectral examination will give information of the temperature structure of the atmosphere. New techniques of solving the associated inverse problems are promising.^{4,5} In addition, the use of land- and space-based microwave scanners of the ocean surface itself may eventually permit direct observation of surface advection currents.

In order to achieve a sufficiently broad theoretical framework for the preceding microwave observations, we must increase the scope of the classical equation of transfer from its present form (which includes thermal radiation) to one that also describes the radiance of a partially coherent field of electromagnetic waves in a scattering-absorbing medium.^{6,7,8,9}

The reader who comes upon these six volumes of *Hydrologic Optics* should, after having perused the above remarks, view this work not as a record of closed and completed research in radiative transfer theory, but simply as one step in a long sequence of steps in our quest for understanding the dynamics of the world we live in. I dedicate this work to all scientists who may find it of help in their individual quests and studies, and in particular to the memory of my mentor during my early years at Scripps Institution of Oceanography, Professor Carl Eckart.

I acknowledge my gratitude, for years of counsel and contractual support (Bureau of Ships, Office of Naval Research) during the formation and writing of this work (1952-69) to Professor S. Q. Duntley of the Visibility Laboratory, Scripps Institution of Oceanography. My thanks also go to Mr. John E. Tyler of the Visibility Laboratory for his contractual support (National Science Foundation) and for providing the inspiration, based on real world data, leading to many parts of the

theory presented in this work. These volumes in their present form, and in their wide distribution, would not have been possible but for the generous support and services provided by the Late Dr. Gaylord Miller, director of the Honolulu-based Joint Tsunami Research Effort of the Pacific Marine Environmental Laboratory, Environmental Research Laboratories, NOAA. I am also grateful that Dr. Miller, over the past six years, had provided an excellent research atmosphere in which I could extend the interaction principles from radiative transfer theory into the field of long ocean surface wave propagation.¹⁰

The final manuscript was typed by Ms. Louise F. Lembeck.

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¹A brief exposition of the salient ideas of the present approach to the statistical radiance problem is given in:

Preisendorfer, R. W., "General Theory of Radiative Transfer Across the Random Atmosphere-Ocean Interface," *J. Quant. Spectrosc. Radiat. Transfer*, 11, 723 (1971).

The references to the published chapters of *Hydrologic Optics* in the above paper are now emended to the present volumes I and VI, published by the Environmental Research Laboratories of NOAA (1976).

²The role of modern radiative transfer theory in the atmosphere is outlined in:

"Problems of Atmospheric Radiation in GARP," GARP Publications Series No. 5, July 1970, World Meteorological Organization, Case postale No. 1, CH-1211 Geneva 20, Switzerland.

³A more general overview of the role of modern radiative transfer theory in the problem of weather and climate prediction is given in:

"The Physical Basis of Climate and Climate Modelling," GARP Publications Series No. 16, April 1975 (address as in 2).

In both GARP publications the need is stressed for numerical methods of radiative transfer which appear to be available now in the present work on *Hydrologic Optics*.

⁴In particular the work of:

Chahine, M. T., "An Analytical Transformation for Remote Sensing of Clear-Column Atmospheric Temperature Profiles," *J. Atm. Sci.*, 32, 1946 (1975),

and its references lead to useful approaches to the inverse temperature problem.

⁵A new approach to the inverse temperature problem is based on invariant imbedding methods wherein the integral equation of the first kind governing the temperature function is solved after being reduced to an initial value problem:

Kagiwada, H. H., Kalaba, R. E., "New Methods for Atmospheric Temperature Inversion" Rand Corporation Report R-1810-DOC, October 1975 (prepared for the Department of Commerce).

⁶See closing paragraph of Bibliographic Notes for Chapter 13, below.

⁷A possible way of building a bridge from electromagnetic theory to radiative transfer theory, in the case of incoherent electromagnetic fields, is sketched in Chapter XIV of [251] (see references at end of this volume).

⁸No comprehensive theory of the scattering of microwaves by the random sea surface seems to be available at present. The work in:

Beckmann, P., and Spizzichino, A., *The Scattering of Electromagnetic Waves from Rough Surfaces*, Macmillan, N. Y. (1963).

provides an excellent introduction to the problem. However, the statistical treatment of the problem, the adopted model of the random sea surface, and the form of the adopted electromagnetic equations are all too rudimentary to provide the appropriate framework for the presently envisioned problems. We have in mind a sufficiently detailed model of both the sea and the electromagnetic field that will reproduce not only the equations of Sec. 12.11 below (for visible wavelengths) but also the (as yet) underived corresponding equations for the microwave context. A beginning in this direction may be based on the (still) excellent treatment of the electromagnetic field in Chapters 3, 4, and 5 of:

Silver, S. (Ed.), *Microwave Antenna Theory and Design* (originally Volume 12 in the 1949 Massachusetts Institute of Technology Radiation Laboratory Series) Dover Publications, N.Y. (1965)

along with the instantaneous sea surface model given in (71) of Sec. 12.4 below.

⁹It is possible to derive an integrodifferential equation of transfer for the specific intensity of any field governed by a linear space-time wave operator in a random setting. Such a derivation was carried out, for example, for sound fields in a random sea, in my lectures on:

Geophysical Random Processes, Oceanography course 220, Scripps Institution of Oceanography, spring 1967 (Chapter 9).

The reduced wave equation for the acoustic field is quite similar in form to that for the E-components of the electromagnetic field. Using the approach outlined in notes 7 and 8, above and the techniques explored in these lectures, the requisite generalized transfer equations for microwaves may be forthcoming, which in turn would provide a tool for analyzing and remotely probing the random sea surface. In this connection, the techniques in §63 of the following reference may also be helpful:

Tatarskii, V. I., *The effects of the Turbulent Atmosphere on Wave Propagation*, U.S. Department of Commerce, National Technical Information Service, Springfield, Va. 22151 (1971).

¹⁰For some references to these works, see the Preface to Volume IV, and also Sec. 8.10 of Volume V of *Hydrologic Optics*. Several further studies, conducted at the Joint Tsunami Research Effort, Honolulu, on the transport theory of linear hydrodynamics are being prepared for publication.