MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE

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September 1, 1978 to August 31, 1984

Dr. B. R. Junker, Contract Monitor
Code 421
Director, Physics Program
Physical Sciences Division
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217

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# Title

MULTIPLE SCATTERING EFFECTS ON TRANSMISSION THROUGH THE ATMOSPHERE

# Keywords

Transmission of optical waves through atmosphere, multiple scattering effects
fog, clouds, rain, hail, snow, Monte-Carlo solution, turbulence, diffusion of
light pulse, radiative transfer theory, forward scatter theory, beam waves,
Henyey-Greenstein scattering pattern, angular broadening, pulse broadening,
coherence bandwidth, coherence time.

# Abstract

This final report gives a summary of the work completed on the contract
covering the period from September 1, 1978 to August 31, 1984. The work is
directed to the investigation of the transmission characteristics of optical
waves with wavelengths in the range of 1-15 μ through various atmospheric
conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers.

Akira Ishimaru

University of Washington
Department of Electrical Engineering, FT-10
Seattle, WA 98195

Office of Naval Research
Physics Program Office
Arlington, VA 22217

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Distribution/Availability Codes

A/1 Special

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directed to the investigation of the transmission characteristics of optical
waves with wavelengths in the range of 1-15 μ through various atmospheric
conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers.
1. **Principal Investigator:** Akira Ishimaru

2. **Contract Description**
   
   This contract is directed to the investigation of the transmission characteristics of a wave with the wavelengths in the range of 1 μm to 15 μm through various atmospheric conditions including clouds, fog, turbulence, rain, hail, snow, and inhomogeneous layers.

3. **Summary of Progress**
   
   Optical propagation in the atmosphere is greatly affected by various particulate matter such as clouds, fog, rain, hail, snow, turbulence, and inhomogeneous layers. Our study has been centered on the wave characteristics in particulate matter. Our progress in this area includes the following:
   
   (a) **Pulse Propagation and Scattering in Particulate Matter** [1-3,5,6,11]

   Pulse broadening due to various particulate matter in the atmosphere is important in determining the data transmission rate of communications. We have conducted fundamental studies on this problem. The backscattering of pulses from discrete scatterers is experimentally and theoretically studied [1]. A theoretical study on the backscattering of a pulse from turbulence is made using small angle approximations [2]. It was observed experimentally [3] that the diffused pulse propagates with a reduced speed. A general summary of the pulse problems is given in [5] and [6]. More refined pulse experiments are reported in [11].
(b) Coherent Wave Propagation in Discrete Scatterers [7,10,13]

One of the fundamental questions relating to the wave propagation in discrete scatterers is the determination of the propagation constant for the average (coherent) field. For a tenuous medium, the propagation constant is given by the classic Van de Hulst formula. However, when the volume density is one percent or higher, the propagation constant is not linearly dependent on the density. There have been extensive theoretical investigations on these multiple scattering effects. We made the first detailed controlled experimental study [7,10,13] using optical and ultrasound scattering techniques. We have thus established an important and useful benchmark for further theoretical study.

(c) Incoherent Wave Characteristics [4,8,9]

The wave in discrete scatterers may be classified into "coherent" and "incoherent" waves. The incoherent field is responsible for backscattering, depolarization, and diffusion. We have carefully examined these multiple scattering effects due to rain [4] and due to fog [8]. We have made careful experimental studies of a beam wave and compared them with the diffusion theory and the first-order scattering theory [9].

(d) Backscattering Enhancement [12]

Backscattering is important in radar and lidar applications. We observed a sharp peak of the order of 1 degree or less in the backscattering direction [12]. This appears to be caused by the second- and higher-order multiple scattering and the coherent length of the order of the mean free path. This interesting phenomenon may be potentially important in practical applications. We are continuing the detailed study of this effect.
4. Publications

Journal Publications with ONR Sponsorship


4. Publications - continued

Paper Presentations Related to the Contract Since September 1978


10. A. Ishimaru was invited to speak at the Chemical Systems Laboratory Scientific Conference on Obscuration and Aerosol Research, U.S. Army, Aberdeen Proving Ground, Maryland, September 1979.


12. A. Ishimaru was invited to speak on "Theoretical and experimental study of transient phenomena in random media" at the workshop on "Wave Propagation in Turbulent Media" sponsored by the Mathematics Division, U.S. Army Research Office, at Virginia Polytechnic Institute, Virginia, March 24-27, 1980.
4. Publications - continued

Paper Presentations Related to the Contract Since September 1978


18. A. Ishimaru, "Multiple scattering effects on optical propagation in turbulence and particles," NATO-AGARD Meeting, Monterey, California, April 1981.


4. **Publications - continued**

**Paper Presentations Related to the Contract Since September 1978**


4. **Publications - continued**

**Paper Presentations Related to the Contract Since September 1978**


5. **Personnel**

   **Graduate Students:**
   
   (a) Koichi Shimizu
   (b) Raymond Chan
   (c) João Machado
   (d) Kirk Painter
   (e) Rudolf Cheung
   (f) Yasuo Kuga
   (g) H. W. Chang

6. **Graduate Students Who Have Earned Advanced Degrees**

   (a) Kirk Painter, M.S. in E.E., Fall 1978
   (b) Koichi Shimizu, Ph.D. in E.E., Summer 1979
   (c) Raymond Chan, M.S. in E.E., Fall 1980
   (d) Rudolf Cheung, Ph.D. in E.E., Fall 1981
   (e) Yasuo Kuga, Ph.D. in E.E., Fall 1983
   (f) João Machado, Ph.D. in E.E., Fall 1983