Laser Monitoring of the Atmosphere

Edited by E. D. Hinkley

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Preface

There is a growing need for continuous monitoring of atmospheric constituents. This has been emphasized recently by the controversy over potentially adverse effects of high-flying aircraft, space shuttles, and even aerosol spray propellants on the life-sustaining ozone layer in the stratosphere. Moreover, the widespread use of more polluting fuels due to dwindling energy resources may produce serious consequences (such as reducing the amount of useful solar energy reaching the earth's surface, changing the earth's heat balance, and degrading air quality in the lower atmosphere) which have yet to be fully understood. Mathematical models of the atmosphere are needed in order to be able to predict the environmental impact of increased source pollution and take the necessary corrective action in a timely and cost-effective manner. The development of these models and the associated continuous surveillance require a wide range of monitoring capabilities.

Surveillance-type monitoring can usually be performed best, and at least expense, with optical techniques. Laser technology has made great strides recently, and the role of lasers in atmospheric monitoring applications has steadily increased; indeed, all of the major laser schemes proposed for monitoring (based on scattering, fluorescence, absorption, and emission) have now been demonstrated experimentally. It is appropriate, therefore, to devote a volume in this Topics series to the subject of laser monitoring of the atmosphere.

This book describes, in a comprehensive and tutorial manner, the fundamental techniques of laser detection of gases and particles. Each chapter contains basic information such as mathematical expressions for the processes and typical values of relevant parameters, in addition to examples of actual measurements made in the field. Consequently, this book should be a useful reference for working scientists and engineers, and a supplementary text book for graduate and undergraduate courses in environmental studies. The broad scope of laser monitoring can be appreciated if we consider that atoms existing in a layer *above* the stratosphere have been detected and their concentrations measured by ground-based laser systems, and gases have been monitored *within* the stratosphere using a balloon-borne tunable laser system. In

the lower atmosphere, pollutant gases, particles, wind speed, and atmospheric temperature have been monitored remotely using laser techniques; and the development of mathematical models for pollutant transport, dispersion, and conversion has been aided by long-path laser measurements.

Each chapter is devoted to a particular type of laser monitoring; but there is strong continuity between chapters, with many cross-references and a uniform set of symbols, defined in the Introduction (Chapt. 1). Chapter 2 considers the structure of the atmospheric and how laser techniques can fulfill some of the air quality management needs of the future. Chapter 3 discusses atmospheric transmission and the selection of appropriate laser wavelengths. Chapters 4–7 concentrate on specific laser techniques. Safety requirements, which must be considered for active laser monitoring systems, are also discussed.

We now recognize that life on earth is affected, both directly and indirectly, by atmospheric constituents not only near ground level but throughout the rest of the troposphere and stratosphere, and possibly above. For proper surveillance of this vast region at reasonable cost, it is becoming increasingly evident that the capabilities offered by laser monitoring techniques may be the only answer. The authors hope that this book will be a useful guide for the evaluation and development of these future laser monitoring systems.

I am indebted to several colleagues for their helpful ideas and comments; particularly, P. L. KELLEY and W. E. BICKNELL of M.I.T. Lincoln Laboratory, V. E. DERR of the National Oceanographic and Atmospheric Administration, and P. B. RUSSELL of Stanford Research Institute. Sincere appreciation is also expressed to the contributors and their families, and to my own wife and children for their patience and encouragement.

Concord, Mass.
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E. D. HINKLEY

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1. Introduction

E. D. HINKLEY

The importance of lasers to modern scientific research, and their resulting technological applications, has been highlighted in earlier volumes of this *Topics in Applied Physics* series. From initial experiments based on the high intensity of laser radiation emerged studies of the nonlinear properties of materials and useful spectroscopic information on the nature of solids, liquids, and gases. With the development of *tunable* lasers, important advances have been made in the field of high-resolution spectroscopy, as highlighted in Volume 2.

The interaction between electromagnetic radiation and atoms and molecules serves as the basis for using lasers to detect and continuously monitor atmospheric constituents and properties. With the steady increase in industrial activity, power generation, transportation, and other potential sources of air pollution, new techniques for atmospheric monitoring are clearly needed to augment those already in use [1.1, 2]. Most of the present instrumentation is based on sample-extraction methods; there are some notable exceptions, however, involving correlation [1.3], dispersive [1.4], and multi-spectral [1.5] techniques, which involve incoherent (non-laser) electromagnetic radiation. With lasers, however, one generally has greater flexibility of operation and can monitor a wider variety of pollutants due to higher resolution.

All of the basic laser techniques which had been proposed for monitoring atmospheric gases and particles have now been shown to work experimentally. The purpose of this volume is to present a unified, tutorial discussion of these techniques, their applications, and their limitations. Included are examples of results obtained so far (to 1976), so that the reader can evaluate the present capabilities of laser monitoring for specific applications and make extrapolations to the future when improved equipment is available. The reader is also referred to a monograph edited by DERR [1.6] which contains a large number of papers on remote sensing up to 1972, and a recent study by WRIGHT et al. [1.7].

This volume covers the application of laser techniques to the detection and continuous monitoring of particulate matter, aerosols, atoms, and molecules in the atmosphere. The term "atmosphere" is taken to

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