
Founded by H.K.V. Lotsch

Editor-in-Chief: W. T. Rhodes, Atlanta

Editorial Board: T. Asakura, Sapporo
K.-H. Brenner, Mannheim
T. W. Hänsch, Garching
T. Kamiya, Tokyo
F. Krausz, Vienna and Garching
B. Monemar, Linköping
H. Venghaus, Berlin
H. Weber, Berlin
H. Weinfurter, Munich

Springer Series in OPTICAL SCIENCES

Volume 1

1 Solid-State Laser Engineering

By W. Koechner, 5th revised and updated ed. 1999, 472 figs., 55 tabs., XII, 746 pages

Published titles since volume 80

80 Optical Properties of Photonic Crystals

By K. Sakoda, 2nd ed., 2004, 107 figs., 29 tabs., XIV, 255 pages

81 Photonic Analog-to-Digital Conversion

By B.L. Shoop, 2001, 259 figs., 11 tabs., XIV, 330 pages

82 Spatial Solitons

By S. Trillo, W.E. Torruellas (Eds.), 2001, 194 figs., 7 tabs., XX, 454 pages

83 Nonimaging Fresnel Lenses

Design and Performance of Solar Concentrators

By R. Leutz, A. Suzuki, 2001, 139 figs., 44 tabs., XII, 272 pages

84 Nano-Optics

By S. Kawata, M. Ohtsu, M. Irie (Eds.), 2002, 258 figs., 2 tabs., XVI, 321 pages

85 Sensing with Terahertz Radiation

By D. Mittleman (Ed.), 2003, 207 figs., 14 tabs., XVI, 337 pages

86 Progress in Nano-Electro-Optics I

Basics and Theory of Near-Field Optics

By M. Ohtsu (Ed.), 2003, 118 figs., XIV, 161 pages

87 Optical Imaging and Microscopy

Techniques and Advanced Systems

By P. Török, F.-J. Kao (Eds.), 2003, 260 figs., XVII, 395 pages

88 Optical Interference Coatings

By N. Kaiser, H.K. Pulker (Eds.), 2003, 203 figs., 50 tabs., XVI, 504 pages

89 Progress in Nano-Electro-Optics II

Novel Devices and Atom Manipulation

By M. Ohtsu (Ed.), 2003, 115 figs., XIII, 188 pages

90/1 Raman Amplifiers for Telecommunications 1

Physical Principles

By M.N. Islam (Ed.), 2004, 488 figs., XXVIII, 328 pages

90/2 Raman Amplifiers for Telecommunications 2

Sub-Systems and Systems

By M.N. Islam (Ed.), 2004, 278 figs., XXVIII, 420 pages

91 Optical Super Resolution

By Z. Zalevsky, D. Mendlovic, 2004, 164 figs., XVIII, 232 pages

92 UV-Visible Reflection Spectroscopy of Liquids

By J.A. Rätty, K.-E. Peiponen, T. Asakura, 2004, 131 figs., XII, 219 pages

93 Fundamentals of Semiconductor Lasers

By T. Numai, 2004, 166 figs., XII, 264 pages

Claus Weitkamp
Editor

Lidar

Range-Resolved Optical Remote Sensing of the Atmosphere

Foreword by Herbert Walther

With 162 Illustrations

 Springer

Dr. Claus Weitkamp
GKSS-Forschungszentrum
Institut für Küstenforschung
Max-Planck-Straße
21502 Geesthacht
Germany

Library of Congress Cataloging-in-Publication Data

LIDAR : range-resolved optical remote sensing of the atmosphere / Claus Weitkamp,
editor ; foreword by Herbert Walther.
p. cm. -- (Springer series in optical sciences, ISSN 0342-4111 ; 102)
Includes bibliographical references and index.
ISBN 0-387-40075-3 (acid-free paper)
1. Atmosphere -- Laser observations. 2. Atmospheric physics -- Remote sensing. 3. Optical
radar -- Observations. I. Weitkamp, Claus. II. Springer series in optical sciences ; v. 102.

QC976.L36L56 2005
551.5'028 -- dc22

2004052454

ISBN 0-387-40075-3

Printed on acid-free paper.

© 2005 Springer Science+Business Media Inc.

All rights reserved. This work may not be translated or copied in whole or in part without the written permission of the publisher (Springer Science+Business Media, Inc., 233 Spring Street, New York, NY 10013, USA), except for brief excerpts in connection with reviews or scholarly analysis. Use in connection with any form of information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed is forbidden. The use in this publication of trade names, trademarks, service marks, and similar terms, even if they are not identified as such, is not to be taken as an expression of opinion as to whether or not they are subject to proprietary rights.

Printed in Singapore

9 8 7 6 5 4 3 2 1 SPIN 10929919

springeronline.com

Foreword

Soon after the laser was invented it became obvious that this new instrument, providing visible and infrared radiation with high intensity density and small divergence, would be a great tool for remote monitoring of atmospheric properties by radar-like methods. The lidar method (li for light instead of ra for radio) is thus practically as old as the laser itself. In the beginning, measurements using light scattering of aerosols and dust particles were at the focus of attention, e.g., for investigating visibility or cloud heights. As lasers became more intense, and systems for detecting backscattered light more sensitive, Rayleigh scattering was also studied to allow parameters such as variation of the total air pressure or clear air turbulence to be investigated. Furthermore, Raman scattering allowed limited selective detection of gas constituents of the atmosphere. Increasing sophistication of laser systems made it possible to study trace constituents of the atmosphere; this was the case as soon as frequency-tunable laser systems, either line-tunable or continuously tunable, became available. This made selective absorption and fluorescence accessible for detecting trace constituents with a sensitivity sufficiently high to be useful.

Improved methods such as the differential absorption method were also invented and used to monitor trace constituents over large distances. In this way, the stratospheric ozone concentration, for example, could be monitored with good accuracy and also checked by comparison with the results of other methods applied simultaneously. Today lidar ozone measurements are being routinely applied by many laboratories in the world.

Not only were laser systems improved in respect to sophistication, they also became more reliable and more efficient, so that finally, long-term routine use was possible and mobile systems, especially advantageous for pollution monitoring, came into use. Systems were also applied in airplanes and satellites, thus tremendously increasing the range of application of lidar methods.

Improvement of laser technology was vital in the lidar field. At first, researchers were mainly concerned with keeping the laser of their lidar system working; finally, they were able to concentrate on optimizing the measurement procedure itself and spend the time evaluating their data.

Lidar thus went through many ups and downs. Finally, it can be stated that the technology reached the stage where methods became reliable. With a few exceptions, e.g., the white light femtosecond lidar system, the techniques described in the present book are in principle already mentioned in previous reviews of the field. However, the experience gained in the last few years with the different methods has been hugely extended by progress in laser techniques, so that finally the enormous potential of lidar was recognized.

I am sure that this book will help newcomers to the field to obtain the information necessary for learning about the potential of lidar methods and applying the techniques for making useful measurements. Researchers working in the lidar field will profit from the practice of experienced colleagues who contributed to the book.

Herbert Walther
University of Munich and
Max Planck Institute of Quantum Optics
Garching, August 2004

Preface

This is a book on lidar, an active range-resolving optical remote measurement technique. Lidar allows us to measure, not just “sense,” virtually every property of the atmosphere. Lidar uses as a probe optical radiation, or light, even if this radiation is not always within the limits of the visible part of the spectrum. Lidar, or laser radar, as it is sometimes called, borrows its name from analogy with the better-known radar. There are indeed certain similarities, and yet the full name of which lidar is the acronym, “light detection and ranging,” is more misleading than enlightening.

In the early days lidar was considered a “poor man’s radar,” as one author put it. This is no longer the case. Today’s lidar systems have reached a high degree of maturity and sophistication. They allow scientists to measure a rich variety of atmospheric parameters on a routine basis. Lidars range in size from a shoebox to a 40-foot container. Compared to radar, lidar offers much better sensitivity to aerosols, much better spatial resolution (lateral resolution on the order of one meter at a distance of ten kilometers with no side lobes), and comparable depth and time resolution. Lidars can measure gases which radar cannot. Lidar opens perspectives for the remote, noncontact, range-resolved measurement of the element composition of aerosols and remote chemical analysis of distant targets. As a whole, lidar provides more and different information on the state of the atmosphere. Lidars and radars thus complement each other in an ideal synergism.

This book covers, for each of the major variants of the lidar technique, the underlying physics—how it works, its mathematics—what the relevant equations look like, the basic layout of an instrument, and examples of atmospheric properties that can be determined and atmospheric

processes that can be investigated. Range-finding, bathymetry, active imaging of a remote object (“lidar”), and non-range-resolving remote fluorescence measurements are not described. Also, this is not a book on meteorology, atmospheric chemistry, atmospheric physics, or pollution abatement strategies. Because the book is not a monograph, the relative importance attached by the authors to the different aspects varies: Some chapters are more theoretical, others are more descriptive in nature. Some authors stress the historical development, others devote most of the available space to applications. The style and the use of mathematical symbols are not strictly consistent from one chapter to another, although some uniformity in terminology has been achieved.

The first two chapters after the introduction each review a phenomenon of particular importance to lidar, namely, depolarization and multiple scattering. The following chapters are devoted either to a lidar variant that is based on one type of interaction such as elastic scattering, absorption, or Raman scattering, or to the measurement of one particular atmospheric property (visibility, moisture). Some of the chapters contain original material that cannot be found in books or archival journals, but is presented here for the first time. I should like to depict this with a few examples.

For example, in the chapter on polarization (Chapter 2), the contents of Figures 2.3, 2.4, and 2.5, the discussion about Saharan dust in Florida, and the description of the effect of clouds are original material, although some of it has been used in articles that are about to appear or have appeared recently. Chapter 3, on multiple scattering, is another example. It is the first known attempt to assemble in logical sequence, under a single cover, our current knowledge on modeling, correcting for, and exploiting multiple scattering in lidar. The material discussed was hitherto dispersed in numerous publications, and some of it was not very well known and consequently little used; an example is the effective-medium theorem of Section 3.3.3, which not only constitutes an important theoretical result by itself but allows considerable simplifications in practical applications. Chapter 4 is a review of the formidable efforts made to extract aerosol microphysical data from lidar signal profiles. Whereas the (forward) calculation of an expected lidar signal from a given profile of aerosol properties is straightforward, the inverse problem, ill posed in mathematical terms, is nevertheless successfully tackled. The description of these efforts in a balanced, comprehensible representation is not found elsewhere in the literature. The same applies to the use of Raman

scattering and high-spectral-resolution lidar (Chapter 5) for the determination of aerosol properties. Visual range is a quantity that is clearly defined, yet in different ways for different applications. These definitions are presented here in a clear-cut, yet concise, approach. The visibility chapter (Chapter 6) is thus more a description of the actual state of the art, stressing modern developments such as the intelligent automobile taillight, heliport (miniaturized) visibility lidar for quicker helicopter rescue logistics, and a soon-to-come web-based, real-time, global-coverage cloud-bottom-height and visibility-profile information network. Chapter 7, on differential-absorption lidar (DIAL), also strongly exhibits a review character, grouping techniques according to wavelength and, within one wavelength range, history; this representation was chosen because techniques differ greatly with wavelength range. Chapter 8, also on DIAL, deals with two gases only but two that are particularly hard to measure. It therefore contains the in-depth treatment of effects important for water vapor and oxygen DIAL and present, although of lesser importance, in DIAL of other gases as well. In Chapter 9, the equations that describe Raman scattering are reformulated with special emphasis on the needs of the lidar scientist. In doing so, the author also implemented the transition from the cgs to the SI system of units. Again, this work has not been published elsewhere. The same applies to the comprehensive theory and performance simulations of Chapter 10 on temperature measurements with lidar in general and rotational Raman lidar in particular; the complete optimization calculations are made available here for the first time. Chapters 11 and 12, on fluorescence lidar and Doppler wind lidar, are kept relatively short, describing the mechanisms and general features of the techniques, but still giving a very few examples of applications: composition, wind, temperature of the upper atmosphere, gravity waves, and meteor science in the case of fluorescence lidar; clear-air turbulence, wind turbines, aviation safety, weather forecasting, and other synergisms for Doppler wind lidar. Chapter 13 is a survey of airborne and spaceborne lidars and their applications, past, present, and future. Again, we know of no other similarly comprehensive review of the subject. Chapter 14, finally, presents two examples of recent lidar developments. For the first, broadband-emission lidar with narrow-band determination of absorption, the complete theory is shown here for the first time. The second, terawatt-femtosecond white-light lidar, opens a path to the remote determination of hitherto inaccessible properties and offers exciting perspectives for atmospheric research through qualitatively new applications of remote measurement technology.

The idea of the book was first discussed in a round-table meeting on the occasion of the Twenty-First International Laser Radar Conference in Quebec City, Quebec, Canada, on 12 July 2002. The time it took to publish the book may appear quite long. In view of the workload imposed today on researchers in science and technology it is amazing that it did not take longer and, more important, that all relevant variants of lidar could be covered.

The authors come from five different nations. They are all world-renowned lidar experts. However, the origin of the authors of this book has nothing to do with the effort and ingenuity devoted by different countries to work in the field. Otherwise, such important lidar nations as Britain, China, Italy, the Netherlands, Russia, Sweden, and Switzerland would not be unrepresented, to name just a few. The same is true for the citations in the different chapters: space did not allow reference to all important contributions, so even some of the most significant, pioneering work had to be left out.

Support by GKSS during the preparation of the manuscript is gratefully acknowledged. Still, this book would not have come into existence without many fruitful discussions with colleagues at Geesthacht and elsewhere. Most authors took a greater than usual interest in the progress of the book, providing, in addition to their manuscripts, many useful suggestions, help, confidence, and moral support. The same is true of Hans Koelsch, volume editor of the publishing company. I thank them all.

Claus Weitkamp
Geesthacht, Germany
December 2004

Contents

Foreword	v
Preface	vii
List of Contributors	xix
1 Introduction to Lidar	
<i>Ulla Wandinger</i>	1
1.1 Lidar and the Atmosphere	1
1.2 Lidar History	2
1.3 Lidar Setup	3
1.4 Lidar Equation	6
1.5 Lidar Techniques and the Contents of This Book ...	12
References	18
2 Polarization in Lidar	
<i>Kenneth Sassen</i>	19
2.1 Introduction	19
2.2 Measures of Depolarization and Their Uncertainties	20
2.3 Causes of Lidar Depolarization: Approximate	
Theories	23
2.4 Lidar Depolarization in the Atmosphere	26
2.4.1 Pure Molecular Scattering	26
2.4.2 Aerosol Scattering	27
2.4.3 Clouds of the Middle and Upper	
Atmosphere	27
2.4.4 Water Cloud Scattering	28
2.4.5 Ice Cloud Scattering	29

2.4.6	Mixed-Phase Clouds	31
2.4.7	Precipitation Scattering	31
2.5	Notable Applications in the Field	33
2.6	Outlook and Conclusions	39
	References	40
3 Lidar and Multiple Scattering		
	<i>Luc R. Bissonnette</i>	43
3.1	Pertinence of Multiple Scattering	44
3.2	Experimental Evidence	50
3.3	Modeling	58
3.3.1	Monte Carlo Methods	60
3.3.2	Stochastic and Phenomenological Methods	64
3.3.3	QSA Approximation—General Theorem	68
3.3.4	QSA Approximation—A Neumann Series Solution	78
3.3.5	QSA Approximation—Analytic Solutions	79
3.3.6	QSA Approximation—A Semiempirical Solution	82
3.3.7	Diffusion Limit	84
3.3.8	Summary	88
3.4	Accounting for Multiple Scattering	89
3.5	Inverse Problem	91
3.5.1	Particle Size Distribution	91
3.5.2	Extinction and Effective Particle Size	95
3.5.3	Bulk Properties	99
	References	100
4 Lidar and Atmospheric Aerosol Particles		
	<i>Albert Ansmann and Detlef Müller</i>	105
4.1	Introduction	105
4.2	Determination of Optical Parameters of Atmospheric Particles	109
4.2.1	Elastic-Backscatter Lidar	109
4.2.2	Raman Lidar and HSRL	112
4.3	Retrieval of Physical Properties of Atmospheric Particles	117
4.3.1	Tropospheric Particles	119
4.3.2	Stratospheric Particles	129

4.4	Measurement Examples	132
4.4.1	Indo-Asian Haze Over the Tropical Indian Ocean	132
4.4.2	Mount–Pinatubo Aerosol Layer	135
	References	138
5 High Spectral Resolution Lidar		
	<i>Edwin E. Eloranta</i>	143
5.1	Introduction	143
5.2	The Principle of High Spectral Resolution Lidar ...	145
5.3	HSRL Implementations	147
5.3.1	Scanning Fabry–Perot Interferometer	147
5.3.2	Fixed Fabry–Perot Interferometer	148
5.3.3	Atomic and Molecular Absorption Filters ...	149
5.4	HSRL Designed for Remote Operation	151
5.4.1	Transmitter	153
5.4.2	Receiver	153
5.4.3	Calibration	155
5.5	Data Examples	157
5.6	Future Prospects	161
	References	163
6 Visibility and Cloud Lidar		
	<i>Christian Werner, Jürgen Streicher, Ines Leike, and Christoph Münk</i>	165
6.1	Introduction	165
6.2	The Notion of Visual Range	166
6.2.1	Normal Visual Range	167
6.2.2	Meteorological Optical Range	167
6.2.3	Vertical Optical Range	167
6.2.4	Slant Optical Range	168
6.2.5	Runway Visual Range, Slant Visual Range ..	168
6.3	Visibility Measurements with Lidar	168
6.4	Aerosol Distributions	170
6.5	Visibility and Multiple Scattering	173
6.6	Instruments	175
6.7	Applications	176
6.7.1	Meteorological Optical Range (MOR) at Hamburg Airport	176
6.7.2	Slant Visibility (SOR) at Quickborn	177

6.7.3	Detection of Clouds	177
6.7.4	Cloud Ceiling	179
6.7.5	Mass Concentration Measurements	181
6.8	Recent Developments	182
6.8.1	Intelligent Taillight: Adaptation of Brightness Using the Lidar Technique	182
6.8.2	Miniaturized Visual-Range Lidar for Heliports	183
6.9	Summary	185
	References	185
7 Differential-Absorption Lidar for Ozone and Industrial Emissions		
	<i>Gary G. Gimmestad</i>	187
7.1	Introduction	187
7.2	The DIAL Equation	188
7.3	DIAL Systems	196
7.3.1	Ultraviolet DIAL Systems	196
7.3.2	Visible-Light DIAL Systems	200
7.3.3	Mid-Infrared DIAL Systems	202
7.3.4	Far-Infrared DIAL Systems	203
7.4	Multi-Wavelength DIAL	206
7.5	Outlook and Conclusions	209
	References	210
8 Differential-Absorption Lidar for Water Vapor and Temperature Profiling		
	<i>Jens Bösenberg</i>	213
8.1	Introduction	213
8.2	Methodology	214
8.2.1	Spectroscopy	215
8.2.2	Detailed DIAL Methodology	219
8.3	Specific Solutions for Water Vapor DIAL Systems ..	224
8.4	Applications of Water Vapor Profiling	226
8.4.1	Assessment of Accuracy	226
8.4.2	Turbulence Studies in the Atmospheric Boundary Layer	230
8.4.3	Airborne Water Vapor Profiling	234
8.5	Temperature Profiling	236
8.6	Conclusions	238
	References	238

9 Raman Lidar

<i>Ulla Wandinger</i>	241
9.1 Introduction	241
9.2 Basic Principles of Raman Scattering	243
9.2.1 Frequency Shifts	243
9.2.2 Cross Sections	245
9.3 Technical Requirements	252
9.3.1 Laser	252
9.3.2 Beam Expander	253
9.3.3 Telescope	254
9.3.4 Receiver Optics	255
9.3.5 Detectors and Data Acquisition	255
9.4 Measurement of Water Vapor	256
9.4.1 Mixing Ratio	256
9.4.2 Calibration	258
9.4.3 Errors	259
9.4.4 Example	261
9.5 Other Applications	262
9.5.1 Ozone Raman DIAL	262
9.5.2 Measurement of Liquid Water	264
9.6 Concluding Remarks	265
References	267

10 Temperature Measurements with Lidar

<i>Andreas Behrendt</i>	273
10.1 Introduction	273
10.2 Overview on Temperature Lidar Techniques	273
10.3 The Integration Lidar Technique	277
10.3.1 Theory	277
10.3.2 Applications	280
10.4 Rotational Raman Lidar	281
10.4.1 Brief Historical Survey	281
10.4.2 Theory	283
10.4.3 Technological Considerations	289
10.5 Technical Implementation: Combined Lidar for Temperature Measurements with the Rotational Raman and the Integration Technique	297
10.5.1 State-of-the-Art Performance	300
References	303

11 Resonance Scattering Lidar

<i>Makoto Abo</i>	307
11.1 Introduction	307
11.2 The Mesospheric Na Layer: Methodology and Observations	308
11.3 Observations of Other Metallic Layers	315
11.4 Measurements of Temperature and Wind with Resonance-Scattering Lidar	317
11.5 Summary and Future Prospects	320
References	321

12 Doppler Wind Lidar

<i>Christian Werner</i>	325
12.1 Introduction	325
12.2 The Optical Doppler Effect	326
12.3 Brief Overview of Wind Lidar Measurement Schemes	328
12.3.1 Crosswind Determination by Pattern Correlation	329
12.3.2 Laser Time-of-Flight Velocimetry (LTV) ...	330
12.3.3 Laser Doppler Velocimetry (LDV)	330
12.3.4 Continuous-Wave Doppler Lidar	331
12.3.5 Pulsed Doppler Lidar	331
12.4 Doppler Wind Lidar Detection and Scan Techniques	332
12.4.1 Wavelength Considerations	332
12.4.2 Detection Techniques	332
12.4.3 Scan Techniques	338
12.5 Systems and Applications	342
12.5.1 Direct-Detection Lidar of the OHP	343
12.5.2 Boundary-Layer Flow Measurements with the NOAA Heterodyne Doppler Wind Lidar ...	343
12.5.3 Airborne Heterodyne Lidar Within the WIND Project	344
12.5.4 Ground-Based Continuous-Wave Heterodyne Lidar for the Measurement of Wake Vortices	347
12.5.5 Clear-Air Turbulence	348
12.5.6 Remote Wind Speed Measurements for Wind Power Stations	349
12.6 Future Developments	350
12.6.1 Instruments	350

12.6.2 Weather Forecast	352
12.6.3 Standardization	352
References	353
13 Airborne and Spaceborne Lidar	
<i>M. Patrick McCormick</i>	355
13.1 Introduction	355
13.2 History of Airborne Lidar	355
13.3 History of Spaceborne Lidars	358
13.4 The Use of Airborne Lidar	360
13.4.1 Elastic Backscatter	361
13.4.2 Resonance Fluorescence	363
13.4.3 Raman Scattering	363
13.4.4 Differential Absorption	364
13.5 The Use of Spaceborne Lidars	368
13.5.1 The LITE Experience	368
13.5.2 ALISSA	380
13.5.3 GLAS	381
13.5.4 CALIPSO	384
13.6 The Future	390
References	392
14 DIAL Revisited: BELINDA and White-Light Femtosecond Lidar	
<i>Felix A. Theopold, Jean-Pierre Wolf, and Ludger Wöste</i> ..	399
14.1 Introduction	399
14.2 BELINDA—Broadband Emission Lidar with Narrowband Determination of Absorption	401
14.2.1 Scattering Processes	401
14.2.2 Lidar Equations	402
14.2.3 BELINDA	405
14.2.4 Practical Considerations	409
14.3 White-Light Femtosecond Lidar	414
14.3.1 Non-Linear Propagation of Terawatt Pulses ..	414
14.3.2 The TERAMOBILE Project	421
14.3.3 White-Light Femtosecond Lidar Measurements	423
14.3.4 Nonlinear Interactions with Aerosols	430
14.4 Conclusion	439
References	441

List of Contributors

Professor Dr. Makoto Abo, Graduate School of Electrical Engineering, Tokyo Metropolitan University, 1-1 Minami-Ohsawa, Hachioji-shi, Tokyo 192-0397, Japan

Dr. Albert Ansmann, Leibniz Institute for Tropospheric Research, Permoserstraße 15, D-04318 Leipzig, Germany

Dr. Andreas Behrendt, Universität Hohenheim, Institut für Physik und Meteorologie, Garbenstraße 30, D-70599 Stuttgart, Germany

Dr. Luc R. Bissonnette, Defence Research & Development Canada—Valcartier, 2459 Pie-XI Blvd North, Val Bélair (Québec), Canada G3J 1X5

Dr. Jens Bösenberg, Max-Planck-Institut für Meteorologie, Bundesstraße 55, D-20146 Hamburg, Germany

Dr. Edwin E. Eloranta, Space Science and Engineering Center, University of Wisconsin—Madison, 1225 West Dayton Street, Madison, Wisconsin 53706, U.S.A.

Professor Dr. Gary G. Gimmestad, Electro-Optics, Environment, and Materials Laboratory, 925 Dalney Street, Georgia Institute of Technology, Atlanta, Georgia 30332-0834, U.S.A.

Dr. Ines Leike, Institut für Physik der Atmosphäre, DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. Oberpfaffenhofen, D-82234 Wessling, Germany

Professor Dr. M. Patrick McCormick, Hampton University, Center for Atmospheric Sciences, 23 Tyler Street, Hampton, Virginia 23668, U.S.A.

Dr. Detlef Müller, Leibniz Institute for Tropospheric Research, Permoserstraße 15, D-04318 Leipzig, Germany

Christoph Münk, Vaisala GmbH, Schnackenburgallee 41d, D-22525 Hamburg, Germany

Professor Dr. Kenneth Sassen, 903 Koyukuk Drive, Geophysical Institute, University of Alaska Fairbanks, Fairbanks, Alaska 99775, U.S.A.

Jürgen Streicher, Institut für Physik der Atmosphäre, DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. Oberpfaffenhofen, D-82234 Wessling, Germany

Dr. Felix A. Theopold, Institut für Küstenforschung, GKSS-Forschungszentrum Geesthacht GmbH, D-21502 Geesthacht, Germany

Dr. Ulla Wandinger, Leibniz Institute for Tropospheric Research, Permoserstraße 15, D-04318 Leipzig, Germany

Dr. Claus Weitkamp, Institut für Küstenforschung, GKSS-Forschungszentrum Geesthacht GmbH, D-21502 Geesthacht, Germany

Dr. Christian Werner, Dachstraße 36, D-81243 München, Germany

Professor Dr. Jean-Pierre Wolf, LASIM (UMR 5579), B. A. Kastler, Université Claude Bernard Lyon 1, F-69622 Villeurbanne Cedex, France

Professor Dr. Ludger Wöste, Institut für Experimentalphysik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany