Wiley Series in Atmospheric Physics and Remote Sensing

Edited by
and J.-L. Brenguier

WILEY-VCH

Airborne Measurements for Environmental Research

Methods and Instruments

Edited by Manfred Wendisch and Jean-Louis Brenguier

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WILEY-VCH Verlag GmbH & Co. KGaA

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A book of the Wiley Series in Atmospheric Physics and Remote Sensing

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Cover Picture

Photo taken near the Caribbean island of Antigua from the University of Wyoming King Air research aircraft during the Rain in Cumulus over the Ocean (RICO) project (funded by the US National Science Foundation). Courtesy of Gabor Vali.

Library of Congress Card No.: applied for

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Bibliographic information published by the Deutsche Nationalbibliothek
The Deutsche Nationalbibliothek lists this publication in the Deutsche Nationalbibliografie; detailed bibliographic data are available on the Internet at <http://dnb.d-nb.de>.

Cover Design Grafik-Design Schulz, Fußgönheim, Germany
Typesetting Laserwords Private Limited, Chennai, India
Printing and Binding Markono Print Media Pte Ltd, Singapore

Print ISBN: 978-3-527-40996-9
ePDF ISBN: 978-3-527-65324-9
ePub ISBN: 978-3-527-65323-2
mobi ISBN: 978-3-527-65322-5
oBook ISBN: 978-3-527-65321-8

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Preface

EUFAR
European Facility
For Airborne
Research

This book summarizes the knowledge of international experts in airborne measurements from 13 countries, which they have developed over many years of field experiments and application to environmental research. The book is produced within the framework of the European Facility for Airborne Research (EUFAR, *http://www.eufar.net/*). EUFAR is a research infrastructure network supported since 2000 by the European Commission, as part of the research infrastructures integration program; see the respective web page at *http://cordis.europa.eu/fp7/capacities/home_en.html.*

One of the EUFAR Networking Activities is dedicated to Expert Working Groups (EWGs), which facilitate cross-disciplinary fertilizations and a wider sharing of knowledge and technologies between academia and industry in the field of airborne research. Over the past 10 years, numerous workshops have been organized by the EWGs addressing technical, logistic, and scientific issues specific to airborne research for the environment. From the beginning, these workshops involved international experts; however, an ever increasing number of scientists from outside the European airborne science community became involved and played an active role. Thus, the EWGs within EUFAR have become a truly international collaborative effort and, as a consequence, the workshops had a continuously increasing impact on defining research foci of future international airborne research.

The EUFAR EWGs currently publish workshop reports and recommendations (i) to aircraft operators on best practice and common protocols for operation of airborne instruments, (ii) to scientific users on best usage and interpretation of the collected data, and (iii) to the research institutions on future challenges in airborne measurements. To ensure legacy of this accumulated knowledge, this book summarizes the major outcome of the EWG discussions on the current status of airborne instrumentation. The book has been designed to provide an extensive overview of existing and emerging airborne measurement principles and techniques. Furthermore, the book analyzes problems, limitations, and mitigation approaches specific to airborne research to explore the environment.

The target audience of the book is not only experienced researchers but also graduate students, the book intends to attract to this exciting scientific field. Also university teachers, scientists experienced in related fields and looking for additional airborne data, for example, for validation or analysis of their own measurements, modelers, and project managers will find a concise overview of airborne scientific instrumentation to explore atmospheric and Earth's surface properties in this book.

Chapter 1 examines the strengths and weaknesses of airborne measurements. The subsequent Chapter 2 deals with the description of instruments to measure aircraft state parameters and basic thermodynamic and dynamic variables of the atmosphere, such as static air pressure, temperature, water vapor, wind vector, turbulence, and fluxes. The next three chapters consider *in situ* measurements of gaseous and particulate atmospheric constituents (Chapters 3–5). Chemical instruments to measure gaseous atmospheric components are introduced in Chapter 3, whereas the instrumentation for particulate atmospheric constituents is described in Chapters 4 (aerosol particles) and 5 (cloud and precipitation particles). Special problems associated with airborne particle sampling (aerosol and cloud/precipitation particles) are discussed in Chapter 6. The following two chapters deal with airborne radiation measurements (Chapter 7) and with techniques for passive remote sensing of the Earth's surface (Chapter 8). The most commonly applied airborne active remote sensing techniques are introduced in Chapter 9. An extensive, albeit not complete, list of references the reader may consult for airborne instrumentation is given at the end of the book. Furthermore, some supplementary material has been compiled, which is not printed but available from the publisher's Web site.

We are very grateful to the European Commission, Research Infrastructure Unit, for its financial support to EUFAR, more specifically for the organization of expert workshops and the preparation of this book. We also acknowledge the support of the national research organizations from Europe and the United States, which are supporting the 91 scientific experts contributing to the book.

We particularly appreciate the considerable efforts of Ulrich Schumann and David W. Fahey to organize and steer the review process for the book; we also acknowledge their useful comments and suggestions. Before publication, the book was peer-reviewed by external experts, which has contributed to improve the quality of the book significantly. We explicitly thank the external reviewers of the book listed in alphabetic order: Charles Brock, Peter Gege, Jim Haywood, Dwayne E. Heard, Jost Heintzenberg, Robert L. Herman, Lutz Hirsch, Andreas

Hofzumahaus, Peter Hoor, Ruprecht Jaenicke, Greg McFarquhar, Matthew McGill, Ottmar Mühler, Daniel Lack, George Leblanc, Hanna Pawlowska, Tom Ryerson, Johannes Schneider, Patrick J. Sheridan, Geraint Vaughan, Peter Vörsmann, and Elliot Weinstock. Technical editor Dagmar Rosenow led many of the thankless but necessary tasks to pull this book together. We are grateful for her talents and dedication, without which the book could not have been completed. We also thank Matt Freer and Frank Werner for their help with editing the text and figures; the students Kathrin Gatzsche and Marcus Kundisch from the Leipzig Institute for Meteorology (LIM) of the University of Leipzig were of great help in compiling the extensive bibliography. Furthermore, we would like to list the leading authors of the chapters emphasizing their active role in writing this book.

Chapter 1: Ulrich Schumann, David W. Fahey, Manfred Wendisch, and Jean-Louis Brenguier
Chapter 2: Jens Bange, Marco Esposito, and Donald H. Lenschow
Chapter 3: Jim McQuaid and Hans Schlager
Chapter 4: Andreas Petzold and Paola Formenti
Chapter 5: Jean-Louis Brenguier
Chapter 6: Martina Krämer, Cynthia Twohy, and Markus Hermann
Chapter 7: Manfred Wendisch and Peter Pilewskie
Chapter 8: Eyal Ben-Dor
Chapter 9: Jacques Pelon and Gabor Vali

Leipzig and Toulouse
2012

Dr. Manfred Wendisch
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and
Dr. Jean-Louis Brenguier
EUFAR coordinator (Météo-France)

A Tribute to Dr. Robert Knollenberg

There have been many important technologies that have been developed for the airborne measurement of atmospheric properties, and the scientific community owes its gratitude to the many distinguished researchers for their significant contributions to the measurement sciences.

One of these people who stands out, in particular, is Robert Knollenberg whose pioneering work in the 1970s led to the development of technology that is still employed in the majority of instruments that make airborne, real-time measurements of size distributions of atmospheric particles, in and out of clouds.

We are paying a special tribute to Robert Knollenberg in this book, the first to present a comprehensive overview of airborne instrumentation for atmospheric measurements, because of his many innovative and creative ideas that have allowed us to study the fine-scale structure of clouds and aerosol particles on a particle-by-particle basis. The development of the optical array probe (OAP), forward scattering spectrometer probe (FSSP), passive cavity aerosol spectrometer probe, single-particle soot photometer, and ultrahigh sensitivity aerosol spectrometer represent cutting-edge technology that has revolutionized how we look at clouds and aerosol particles. These groundbreaking instrument developments allowed the atmospheric science community to understand fundamental physical processes that, while theoretically predicted, could not be observed in the free atmosphere until Knollenberg's instruments provided the technology to measure the necessary particle characteristics to corroborate the theory.

After completing his PhD at the University of Wisconsin with continuous strong guidance from Dr. Robert Graham, Robert Knollenberg spent 3 years at the National Center for Atmospheric Research developing and field testing cloud particle spectrometers. In 1972, he decided to commercialize such instruments for use by the atmospheric community and formed Particle Measuring Systems (PMS) Inc. in Boulder, Colorado (USA). While under his direction, PMS developed a commercial version of the OAP, the 200-X and 200-Y, which were classified as "1D" probes, because they only measured the maximum size of particles with no shape information. This led, however, to the "2D" probes that measured the two-dimensional image of particles. In parallel to these developments, Knollenberg was also implementing single-particle light scattering to build the axially scattering spectrometer probe that evolved into the FSSP. Aside from the atmospheric community's use of these instruments, they became essential for quantifying the cloud structure when certifying aircraft for "flight into known icing conditions."

Knollenberg turned PMS over to other management in the early 1990s to concentrate on research and instrument development, while spinning out a PMS electro-optics division forming another company, Research Electro-Optics Inc., which concentrated on developing new lasers and related optical components needed for PMS instrumentation and more general use. PMS went on to become the industry leader in optical particle counters used by the semiconductor industry to assess clean room and process fluid microcontamination. Knollenberg built the multiangle aerosol spectrometer (MASP) for NASA that was used to derive the size and refractive index of stratospheric aerosol particles while flying on the NASA ER-2. The MASP is the precursor to the cloud and aerosol spectrometer that is currently in use and implements the same measurement approach. Most recently, Knollenberg discovered how to measure the mass concentration of black carbon in individual aerosol particles using the concept of incandescence in an infrared laser cavity, once again breaking new ground and giving researchers a new tool to dissect individual particles and better understand how black carbon affects health and climate.

It is difficult to assess the breadth and depth of knowledge that the community has gained with respect to the science of the atmosphere as a result of Knollenberg's technological contributions. His strong background as an atmospheric physicist allowed him to understand the limitations and uncertainties in the technology that he then removed or minimized with the development of new techniques. Knollenberg serves as an inspiration to all who are interested in understanding how the atmosphere works and in particular to young scientists with new ideas on how to measure the properties of the atmosphere.

It is with deep gratitude that we offer this tribute in his name.

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