Springer Handbook of Atmospheric Measurements

Foken
Editor

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Springer Handbook of Atmospheric Measurements

Thomas Foken (Ed.)

With 752 Figures and 526 Tables

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Editor
Thomas Foken
University of Bayreuth
Bayreuth, Germany

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Foreword

Taking measurements in the atmosphere means to work in a "non-periodic", chaotic environment. Consequently, it is impossible to repeat any measurements under same conditions, because every state of the atmosphere is unique and will never occur again. Another consequence is the basic impossibility to find a representative location for a measurement because of the non-linear scale interaction in the atmosphere. Processes on any scale interacts with those on all other scales. The basic requirement of reproducibility, any laboratory experiment has to meet, can, therefore, never be fulfilled by measurements in the atmosphere.

To address this dilemma atmospheric scientists have learned to think in spatial and time scales and to select such information from measurements which is relevant for the scale of interest. This is achieved by selecting suitable designs of the field experiments, station networks, instrumentation, and data processing. Therefore, the requirements on observation systems and the applied observation technologies are progressing continuously with the state of science and technology.

Gerhard Adrian
President DWD and WMO
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The World Meteorological Organization (WMO) has established under the "WMO Integrated Global Observing System" (WIGOS) a process to monitor these "rolling" requirements and to document them with the web-based "Observing Systems Capability Analysis and Review Tool" (OSCAR). OSCAR provides a structure along scales, applications, and variables and is an open tool to which everybody can contribute.

Systematic meteorological observations were established when scientists began to develop classifications (taxonomies) of natural phenomena. Up to day, we still use a cloud classification scheme inspired by the British pharmacist *Luke Howard*, who developed its basic version at the beginning of the nineteenth century. Meanwhile we have learned to describe and predict the state of the atmosphere with quantitative methods based on physical principles formulated with mathematical equations. Consequently, we are not able today to use phenomenological descriptions anymore. Today we need information on physically well-defined variables. From my perspective, this is the challenge for the further development of observing systems and the required measurement techniques. It is also an opportunity to improve and extend our knowledge about the atmosphere.

This book supplements the guidance provided by the intergovernmental Technical Commission for Observation, Infrastructure and Information Systems (COIIS) of the World Meteorological Organization (WMO), which is tasked as a specialized UN organization "to promote standardization of meteorological and related observations…" (Article 2 of WMO Convention).

Prof. Dr. Gerhard Adrian
President German Meteorological Service (DWD)
and World Meteorological Organization (WMO)

Preface

The *Springer Handbook of Atmospheric Measurements* is the result of many rounds of discussion with renowned scientists and the publisher, with the intention of developing a reference work that comprehensively covers all aspects of measurements in the atmosphere and at its interface with plants, soil, and water, including some general aspects of metrology. I was happy to bring to this project my nearly 50 years of experience in atmospheric measurements, with a strong focus on micrometeorology, and my more than 25 years of experience working in the standardization of meteorological measurements for VDI (The Association of German Engineers) and DIN (the German Institute of Standardization).

Several developments have made this handbook necessary and timely. Most of the classical in-situ instruments have been replaced by electrical measuring devices. Not only has the toxicity of mercury led to international agreements preventing its use in barometers and thermometers, but the reduction in visual weather observations has resulted in a requirement for low-maintenance electrical sensors and automatic stations. Besides the use of discrete sensors for the various meteorological elements at classical weather and climate stations, more compact sensors are now available. These incorporate all of the sensors into a small weather station with dimensions of 10–30 cm. Furthermore, so-called smart sensors with wireless connectivity and satellite positioning data enable anyone to measure meteorological parameters. The issue of quality control is then shifted from the single sensor to the network, and the crowdsourcing approach necessitates intelligent software to separate biased from accurate data.

Remote sensing instruments were the exclusive domain of meteorological services or scientific institutions, but more recently they have—with the exception of some very complicated instruments and instruments that are in development—passed into more general use. Besides weather radar, ceilometers and radar wind profilers have recently become standard instrumentation in meteorological networks. The fast development of the wind power industry has supported the development of Doppler wind lidars, and these instruments have become much smaller and even relatively inexpensive.

Similarly, throughout their long history, meteorological observations have been the task of meteorologists alone—until recently. Nowadays, agencies that carry out environmental monitoring use meteorological data and have their own networks, as does industry. With the ability to measure fluxes, ecologists have become an important group that apply atmospheric measurements. The handbook therefore also includes specific measurements at the interface between the atmosphere and the biosphere and pedosphere.

As already mentioned, quality control and standardization are important procedures for ensuring that highly accurate meteorological information with high spatial resolution is made available. This is not only a task for calibration laboratories. It is important that the developers and implementers of software tools understand the complicated structure of the atmosphere in terms of the vertical and horizontal fields of meteorological elements, particularly in heterogeneous areas such as cities and their surroundings.

This handbook is divided into five parts. Part A is an introduction to the handbook, with chapters covering the structure of the atmosphere, the basics of measurements, the fundamentals of quality control, and the standardization of measurements. Furthermore, quantities that are necessary for measurements in the atmosphere and the soil are provided in abundant tables. Some of those tables are also available online. All quantities are given in accordance with the International Temperature Scale (ITS-90).

Part B includes all in-situ measurement methods, and starts with an overview of ground-based platforms. Besides classical measurements such as temperature, humidity, wind, pressure, radiation, precipitation, and visibility, sensors for electricity, trace gases, aerosols, stable isotopes, and radioactivity are also described. Only basic information is provided for the latter category because other monographs are available for trace gas and aerosol measurements. A final chapter covers the relatively new technique of optical-fiber-based measurements in addition to classical odor and visual observations.

Parts C and D are devoted to remote sensing techniques, which are separated into ground-based and aircraft/satellite-based techniques. An introduction to airborne platforms is included. The discussion of ground-based measurements (Part C) includes sodar, RASS, different types of lidar, radar, scintillometers, spectrometric methods that use light of different wavelengths and microwaves. Furthermore, tomographic methods that use sound waves, and electromagnetic waves of satellite navigation systems, are chapters of the handbook. Because aircraft- and satellite-based methods have become more and more important for analyzing a very large number of meteorological elements and properties of the Earth's surface, they are considered separately in Part D, in spite of some overlap with earlier discussions of lidar, radar, and methods based on microwaves, visible light, or infrared light.

Part E is largely atypical for a book concerning atmospheric measurements. It describes the combination of different sensors for specific applications and measurements at the interface between the atmosphere and the underlying surface. First, horizontally distributed observations—including classical weather stations, crowdsourcing, and mesometeorological networks—are considered, followed by vertical measurement systems such as aerological measurements and composite profiling. Here, horizontally moving systems are aircraft, unmanned aircraft systems, and ground-based moving systems. Subsequent chapters focus on special applications such as measurements of different types of renewable energy and urban measurements, and then on measurement techniques for and applications of fluxes: fog deposition, dry deposition, the eddy-covariance technique and similar measurements, lysimeter and evapotranspiration measurements and calculations, and chamber measurements at plants and the soil surface. Finally, short chapters describe measurements in soil and water.

Part F—the final part of this handbook—discusses networks, which play important roles in rendering measurements comparable and achieving a high standard of measurement quality. The two chapters in Part F give an overview of networks of atmospheric and ecological measurements.

Given the timeframe of the present edition of this handbook, it was not possible to provide complete coverage of all instruments used for atmospheric measurements. However, the editor and Springer are hopeful that, in a future edition, the minor gaps in coverage will be filled by recruiting authors who are able to take on the time-consuming task of providing new chapters on instruments not discussed here.

Some comments on the organization of this handbook may be helpful. Most of the chapters are structured in the same way for easier orientation of the reader, although the subject matter of some chapters meant that they could only broadly follow this schema. Section 1 of each chapter gives a short overview of the measured variables and their dimensions as well as the main measurement principles. Section 2 is a historical part, which we included not only because this is quite interesting but also because many techniques have not been in use for the last 10–50 years. For currently used measurement methods, Section 3 presents the theory and Section 4 the applicable devices. In most of the chapters, the advantages and disadvantages of the various relevant sensors or methods are also listed at the end of Section 4. In the majority of the chapters, Section 5, on specifications, allows the reader to rapidly review the measurement ranges, accuracies, or response times of the devices and methods in tabulated form. Quality control, calibration, and reference standards are discussed in Section 6, and Section 7 gives an overview of necessary maintenance actions along with the appropriate time intervals. Some selected examples of applications of the devices and methods are shown in Section 8, and further developments are discussed in Section 9. Monographs, overview papers, and standards are available for many of the techniques, and these are listed in the Further Reading section. Every chapter ends with a long list of references.

I want to thank the 140 authors and, in particular, the corresponding authors for their significant contributions to this handbook, as well as the more than 60 reviewers for their helpful reviews of all chapters. Many thanks are due to Dr. Judith Hinterberg for developing the concept of the handbook, and to Ursula Barth, both from Springer Nature Heidelberg, for the intensive communication with me and the authors and Jeannette Krause (le-tex, Leipzig) for the preparation of the final manuscript. Last but not least, I thank my wife and our family for their sympathy and support of this project over the last four years.

Bayreuth, Germany Thomas Foken
August 2021

About the Editor

Thomas Foken is retired Professor of Micrometeorology at the University of Bayreuth (Bayreuth Center of Ecology and Environmental Research), Germany. He obtained his doctoral degree (Dr rer nat) from Leipzig University in 1978 and his second doctoral degree (Dr sc nat) from the Humboldt University of Berlin in 1990. He headed the Laboratories of Boundary Layer Research and Land Surface Processes of the Meteorological Service of the GDR and the German Meteorological Service (DWD) at the Observatories at Potsdam (1981–1994) and Lindenberg (1994–1997). In 1997, Thomas Foken was appointed Professor of Micrometeorology at the University of Bayreuth. He has taught courses on micrometeorology in Berlin, Potsdam, and Bayreuth. His main research areas are related to the interaction between the Earth's surface and the atmosphere, and the measurement and modeling of energy and matter fluxes, with a strong focus on measurement devices. He has organized and participated in experiments at the international level, e.g. in Russia, USA, Tibet, and Antarctica. He has published in peer-reviewed journals as well as textbooks and has made significant advancements in the application of the eddy-covariance method. These scientific contributions have been recognized through various awards, including the Dionyz Stur Medal in Silver of the Slovak Academy of Science, the Award for Outstanding Achievements in Biometeorology of the American Meteorological Society, the Honor Badge of the Association of German Engineers (VDI), and Honorary Membership of the Hungarian Meteorological Society. In recent years, he has been consultant for Arctic and forest fire projects, and lecturer at the Eötvös Loránd University Budapest. In Germany, Thomas Foken is responsible for the standardization of atmospheric in-situ measurement techniques (VDI/DIN, ISO). As a specialist for climate and climate change in Northern Bavaria, he is regularly invited to give lectures for school students at events organized by the Fridays for Future movement.

Thomas Foken
(photo: U. Krzywinski)

About the Authors

Bianca Adler
NOAA/Physical Sciences Laboratory
CIRES, University of Colorado Boulder
Boulder, CO, USA
bianca.adler@noaa.gov

Richard Allen
Soil and Water Systems
University of Idaho
Kimberly, USA
rallen@uidaho.edu

Christof Ammann
Climate and Agriculture
Agroscope Research Institute
Zürich, Switzerland
christof.ammann@agroscope.admin.ch

Marc Aubinet
TERRA Teaching and Research Centre
University of Liege
Gembloux, Belgium
marc.aubinet@uliege.be

Jens Bange
Centre for Applied Geo-Science
University of Tübingen
Tübingen, Germany
jens.bange@uni-tuebingen.de

Karsten Baumann
Environmental Sciences and Engineering
University of North Carolina at Chapel Hill
Chapel Hill, USA
kbaumann@unc.edu

Andreas Behrendt
Institute of Physics and Meteorology
University of Hohenheim
Stuttgart, Germany
andreas.behrendt@uni-hohenheim.de

Klaus Behrens
Nuthetal, Germany
klaus.behrens@mailbox.org

Michael Bender
FE12 Datenassimilation
German Meteorological Service (DWD)
Offenbach, Germany
michael.bender@dwd.de

Alec Bennett
Biral
Portishead, UK
alec.bennett@biral.com

Frank Beyrich
Meteorologisches Observatorium Lindenberg –
Richard-Aßmann-Observatorium
Lindenberg, Germany
frank.beyrich@dwd.de

Jacqueline Bieringer
Atmospheric Radioactivity and Trace Analysis
Federal Office for Radiation Protection
Freiburg, Germany
jbieringer@bfs.de

Christina Bogner
Institute of Geography
University of Cologne
Cologne, Germany
christina.bogner@uni-koeln.de

Annette Borowiak
Air and Climate Unit
Joint Research Centre
Ispra, Italy
annette.borowiak@ec.europa.eu

Jerald A. Brotzge
New York State Mesonet
University at Albany
Albany, USA
jbrotzge@albany.edu

Steven S. Brown
NOAA Chemical Sciences Laboratory
Boulder, USA
steven.s.brown@noaa.gov

William Brown
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, USA
wbrown@ucar.edu

Henk A.R. Bruin
Bilthoven, The Netherlands
hardb@xs4all.nl

Matthias Budde
Institute of Telematics, TECO / Chair for Pervasive Computing Systems
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
and
Disy Informationssysteme GmbH
Karlsruhe, Germany
matthias.budde@disy.net

Arianna Cauteruccio
DICCA – Dep. Civil, Chemical and Environmental Engineering
University of Genova
Genova, Italy
arianna.cauteruccio@edu.unige.it

Jan Cermak
Institute of Meteorology and Climate Research and Institute of Photogrammetry and Remote Sensing
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
jan.cermak@kit.edu

Shih-Chieh Chang
Department of Natural Resources and Environmental Studies, Center for Interdisciplinary Research on Ecology and Sustainability
National Dong Hwa University
Hualien, Taiwan
scchang@gms.ndhu.edu.tw

Matteo Colli
DICCA – Dep. Civil, Chemical and Environmental Engineering
University of Genova
Genova, Italy
matteo.colli@unige.it

Heinz Coners
Plant Ecology and Ecosystems Research
University of Göttingen
Göttingen, Germany
hconers@uni-goettingen.de

Susanne Crewell
Institute for Geophysics and Meteorology
University of Cologne
Köln, Germany
susanne.crewell@uni-koeln.de

Matthias Cuntz
UMR Silva
Université de Lorraine, AgroParisTech, INRAE
Nancy, France
matthias.cuntz@inrae.fr

Axel Delan
IFU GmbH Privates Institut für Analytik
Frankenberg, Germany
axel.delan@ifu-analytik.de

Julien Delanoë
LATMOS/IPSL, UVSQ Université Paris-Saclay, Sorbonne Université, CNRS
Guyancourt, France
julien.delanoe@latmos.ipsl.fr

Raymond L. Desjardins
Science and Technology Branch
Agriculture and Agri-Food Canada
Ottawa, Canada
ray.desjardins@canada.ca

Galina Dick
GFZ German Research Centre for Geosciences, Department 1: Geodesy
Helmholtz Centre Potsdam
Potsdam, Germany
galina.dick@gfz-potsdam.de

Anna Dzvonkovskaya
Helzel Messtechnik GmbH
Kaltenkirchen, Germany
dzvonkovskaya@gmail.com

André Ehrlich
Leipzig Institute for Meteorology (LIM)
University of Leipzig
Leipzig, Germany
a.ehrlich@uni-leipzig.de

Scott Ellis
Research Applications Laboratory
National Center for Atmospheric Research
Boulder, USA
sellis@ucar.edu

Stefan Emeis
Institute of Meteorology and Climate Research
Karlsruhe Institute of Technology (KIT)
Garmisch-Partenkirchen, Germany
stefan.emeis@kit.edu

Florian Ewald
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)
Weßling, Germany
florian.ewald@dlr.de

Christopher A. Fiebrich
Oklahoma Mesonet/Oklahoma Climatological Survey
University of Oklahoma
Norman, USA
fiebrich@ou.edu

Anita Flohr
Ocean and Earth Science
University of Southampton
Southampton, UK
a.flohr@southampton.ac.uk

Thomas Foken
University of Bayreuth
Bayreuth, Germany
thomas.foken@uni-bayreuth.de

Wolfgang Foken
Automotive Engineering
University of Applied Sciences in Zwickau
Zwickau, Germany
wolfgang.foken@online.de

Jeffrey French
Department of Atmospheric Science
University of Wyoming
Laramie, USA
jfrench@uwyo.edu

Julia Fuchs
Institute of Meteorology and Climate Research and Institute of Photogrammetry and Remote Sensing
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
julia.fuchs@kit.edu

Masatomo Fujiwara
Faculty of Environmental Earth Science
Hokkaido University
Sapporo, Japan
fuji@ees.hokudai.ac.jp

Ulrich Görsdorf
Meteorologisches Observatorium Lindenberg – Richard Aßmann Observatorium
German Meteorological Service (DWD)
Lindenberg, Germany
ulrich.goersdorf@dwd.de

Sue Grimmond
Department of Meteorology
University of Reading
Reading, UK
c.s.grimmond@reading.ac.uk

Martin Hagen
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)
Weßling, Germany
martin.hagen@dlr.de

Samuel Haimov
Atmospheric Science Department
University of Wyoming
Laramie, USA
haimov@uwyo.edu

R. Michael Hardesty
Cooperative Institute for Research in Environmental Sciences
University of Colorado Boulder
Boulder, USA
r.michael.hardesty@colorado.edu

Giles Harrison
Department of Meteorology
University of Reading
Reading, UK
r.g.harrison@reading.ac.uk

Oscar K. Hartogensis
Environmental Sciences – Meteorology and Air Quality
Wageningen University
Wageningen, The Netherlands
oscar.hartogensis@wur.nl

Matthew Hayman
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, USA
mhayman@ucar.edu

Dwayne Heard
School of Chemistry
University of Leeds
Leeds, UK
d.e.heard@leeds.ac.uk

Andreas Held
Environmental Chemistry and Air Research
Technische Universität Berlin
Berlin, Germany
held@tu-berlin.de

Olaf Hellmuth
Modeling Department
TROPOS Leibniz Institute for Tropospheric Research
Leipzig, Germany
olaf.hellmuth@tropos.de

Gerald Heymsfield
Mesoscale Atmospheric Processes Laboratory
Goddard Space Flight Center
Greenbelt, USA
gerald.heymsfield@nasa.gov

Klaus Heyn
Sensing Technologies
Vaisala GmbH
Hamburg, Germany
klaus.heyn@vaisala.com

Jochen Horstmann
Ocean Surface Dynamics
Institute of Coastal Ocean Dynamics of the
Helmholtz-Zentrum hereon, Germany
Geesthacht, Germany
jochen.horstmann@hereon.de

Bernd Huwe
Soil Physics
University of Bayreuth
Bayreuth, Germany
bernd.huwe@uni-bayreuth.de

Andreas Ibrom
Environmental Engineering
Technical University of Denmark (DTU)
Lyngby, Denmark
anib@env.dtu.dk

Simon Jäckel
VDI e.V. – The Association of German Engineers
Düsseldorf, Germany
jaeckel@vdi.de

Jürgen Junk
Environmental Research and Innovation (ERIN)
Luxembourg Institute of Science and Technology
(LIST)
Belvaux, Luxembourg
juergen.junk@list.lu

Norbert Kalthoff
Institute of Meteorology and Climate Research,
Department Troposphere
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
no.kalthoff@web.de

Ayse Kilic
School of Natural Resources and Dept. Civil
Engineering
University of Nebraska-Lincoln
Lincoln, USA
akilic@unl.edu

Bruce Kindel
Laboratory for Atmospheric and Space Physics
University of Colorado at Boulder
Boulder, USA
bruce.kindel@lasp.colorado.edu

Olaf E. E. Kolle
Field Experiments and Instrumentation
Max-Planck-Institute for Biogeochemistry
Jena, Germany
olaf.kolle@bgc-jena.mpg.de

Christoph Kottmeier
Institute of Meteorology and Climate Research,
Department Troposphere
Karlsruhe Institute of Technology (KIT)
Karlsruhe, Germany
christoph.kottmeier@kit.edu

Lars Kutzbach
Institute of Soil Science
Universität Hamburg
Hamburg, Germany
lars.kutzbach@uni-hamburg.de

Gerhard Lammel
Multiphase Chemistry Department
Max Planck Institute for Chemistry
Mainz, Germany
g.lammel@mpic.de

Luca G. Lanza
DICCA – Dep. Civil, Chemical and Environmental Engineering
University of Genova
Genova, Italy
luca.lanza@unige.it

Volker Lehmann
Meteorologisches Observatorium Lindenberg
German Meteorological Service (DWD)
Lindenberg, Germany
volker.lehmann@dwd.de

Ingeborg Levin
Institut für Umweltphysik
Heidelberg University
Heidelberg, Germany
ingeborg.levin@iup.uni-heidelberg.de

Martin Löffler-Mang
School of Engineering
htw saar, University of Applied Sciences
Saarbrücken, Germany
loeffler-mang@htwsaar.de

Ulrich Löhnert
Institute for Geophysics and Meteorology
University of Cologne
Köln, Germany
ulrich.loehnert@uni-koeln.de

Ian MacPherson
National Research Council of Canada
Ottawa, Canada
ian.macpherson@rogers.com

Alexander Mangold
Scientific Service Observations
Royal Meteorological Institute of Belgium
Brussels, Belgium
alexander.mangold@meteo.be

Matthias Mauder
Institute of Hydrology and Meteorology
Technische Universität Dresden
Dresden, Germany
matthias.mauder@tu-dresden.de

Mario Mech
Institute for Geophysics and Meteorology
University of Cologne
Köln, Germany
mario.mech@uni-koeln.de

Stefan Metzger
National Ecological Observatory Network (NEON); Battelle
Boulder, USA
smetzger@battelleecology.org

Volker Mohrholz
Physical Oceanography and Instrumentation
Leibniz-Institute for Baltic Sea Research Warnemünde
Rostock, Germany
volker.mohrholz@io-warnemuende.de

J. William Munger
John A. Paulson School of Engineering and Applied Sciences
Harvard University
Cambridge, USA
jwmunger@seas.harvard.edu

Christoph Münkel
Vaisala GmbH
Hamburg, Germany
cmuenkel@web.de

Axel Murk
Institute of Applid Physics
University of Bern
Bern, Switzerland
axel.murk@iap.unibe.ch

Sascha Nehr
European University of Applied Sciences
Brühl, Germany
s.nehr@eufh.de

Reinhard Nolz
Institute for Soil Physics and Rural Water Management
University of Natural Resources and Life Sciences, Vienna
Wien, Austria
reinhard.nolz@boku.ac.at

Samuel Ortega-Farias
Research and Extension Center for Irrigation and Agroclimatology (CITRA)
Universidad de Talca
Talca, Chile
sortega@utalca.cl

Eberhard Parlow
Department of Environmental Sciences
Atmospheric Sciences
University Basel
Basel, Switzerland
eberhard.parlow@unibas.ch

Elizabeth Pattey
Science and Technology Branch
Agriculture and Agri-Food Canada
Ottawa, Ontario, Canada
elizabeth.pattey@canada.ca

Kyaw Tha Paw U
Land, Air and Water Resources
University of California
Davis, CA, USA
ktpawu@ucdavis.edu

Andrew L. Pazmany
ProSensing Inc.
Amherst, USA
pazmany@prosensing.com

Oscar Perez-Priego
Biological Science
Macquarie University
Sydney, NSW, Australia
oscarperezpriego@gmail.com

Gerhard Peters
Metek, Meteorologische Messtechnik GmbH
Elmshorn, Germany
peters@metek.de

Ralf Petrich
IFU GmbH Privates Institut für Analytik
Frankenberg, Germany
ralf.petrich@ifu-analytik.de

Rolf Philipona
Federal Office of Meteorology and Climatology
MeteoSwiss
Davos Dorf, Switzerland
rolf.philipona@gmail.com

Peter Pilewskie
Laboratory for Atmospheric and Space Physics and
Department of Atmospheric and Oceanic Sciences
University of Colorado Boulder
Boulder, USA
peter.pilewskie@lasp.colorado.edu

Andreas Platis
Centre for Applied Geo-Science
University of Tübingen
Tübingen, Germany
andreas.platis@uni-tuebingen.de

Christopher Pöhlker
Multiphase Chemistry Department
Max Planck Institute for Chemistry
Mainz, Germany
c.pohlker@mpic.de

Catherine Prigent
LERMA
CNRS, Observatoire de Paris
Paris, France
catherine.prigent@obspm.fr

Armin Raabe
Leipzig Institute for Meteorology (LIM)
University of Leipzig
Leipzig, Germany
raabe@uni-leipzig.de

Corinna Rebmann
Department Computational Hydrosystems
Helmholtz Centre for Environmental Research
Leipzig, Germany
corinna.rebmann@ufz.de

Oliver Reitebuch
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt e. V.
(DLR)
Weßling, Germany
oliver.reitebuch@dlr.de

Sascha Reth
UGT GmbH
Hallbergmoos, Germany
sascha.reth@ugt-online.de

Joachim Reuder
Geophysical Institute, and Bjerknes Centre for
Climate Research
University of Bergen
Bergen, Norway
joachim.reuder@gfi.uib.no

Janne Rinne
Department of Physical Geography and Ecosystem
Science
Lund University
Lund, Sweden
janne.rinne@nateko.lu.se

David Risk
Earth Sciences
St. Francis Xavier University
Antigonish, Canada
drisk@stfx.ca

Christoph Ritter
Physics of the Atmosphere
Alfred-Wegener-Institute
Potsdam, Germany
christoph.ritter@awi.de

Raymond Rülke
Langendorf, Germany

Klaus Schäfer
Atmospheric Physics Consultant
Garmisch-Partenkirchen, Germany
schaefer@atmosphericphysics.de

Robert S. Schemenauer
FogQuest: sustainable water solutions
Kamloops, Canada
fogquest@shaw.ca

Hans Peter Schmid
Institute of Meteorology and Climate Research – Atmospheric Environmental Research
Karlsruhe Institute of Technology (KIT)
Garmisch-Partenkirchen, Germany
hape.schmid@kit.edu

K. Sebastian Schmidt
Laboratory for Atmospheric and Space Physics
University of Colorado at Boulder
Boulder, USA
sebastian.schmidt@lasp.colorado.edu

John Selker
Oregon State University
Corvallis, USA
john.selker@oregonstate.edu

Jörg E.E. Seltmann
Hohenpeissenberg Observatory
German Meteorological Service (DWD)
Hohenpeissenberg, Germany
joerg.seltmann@yandex.com

Dietrich Sonntag
Berlin, Germany

Scott M. Spuler
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, USA
spuler@ucar.edu

Brian Stacey
Ricardo Energy and Environment
Didcot, UK
brian.stacey@ricardo.com

Mattia Stagnaro
DICCA – Dep. Civil, Chemical and Environmental Engineering
University of Genova
Genova, Italy
mattia.stagnaro@unige.it

Manuela Starke
Chair of Meteorology
Technische Universität Dresden
Tharandt, Germany
manuela.starke@tu-dresden.de

Thomas Steinkopff
Surveillance of Radioactivity
German Meteorological Service (DWD)
Offenbach, Germany
tommy_theater@t-online.de

Ulrich Stöhlker
IMIS measurement tasks
Federal Office for Radiation Protection
Freiburg, Germany
ustoehlker@bfs.de

Cove Sturtevant
National Ecological Observatory Network (NEON); Battelle
Boulder, USA
csturtevant@battelleecology.org

Jens-Arne Subke
Biological and Environmental Sciences
University of Stirling
Stirling, UK
jens-arne.subke@stir.ac.uk

Christoph K. Thomas
Micrometeorology
University of Bayreuth
Bayreuth, Germany
christoph.thomas@uni-bayreuth.de

Anni Torri
Vaisala Oyj
Vantaa, Finland
anni.torri@vaisala.com

Ivonne Trebs
Environmental Research and Innovation (ERIN)
Luxembourg Institute of Science and Technology (LIST)
Belvaux, Luxembourg
ivonne.trebs@list.lu

Ricardo Trezza
California Irrigation Management Information System (CIMIS)
California Department of Water Resources
Sacramento, USA
ricardo.trezza@water.ca.gov

Isabel F. Trigo
Portuguese Institute for the Sea and the Atmosphere (IPMA)
Lisboa, Portugal
isabel.trigo@ipma.pt

Holger Vömel
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, USA
voemel@ucar.edu

Emanuele Vuerich
Italian Air Force
Rome, Italy
emanuele.vuerich@aeronautica.difesa.it

Helen C. Ward
Department of Atmospheric and Cryospheric Sciences
University of Innsbruck
Innsbruck, Austria
helen.ward@uibk.ac.at

Konradin Weber
Laboratory for Environmental Measurement Techniques
Duesseldorf University of Applied Sciences
Duesseldorf, Germany
konradin.weber@hs-duesseldorf.de

Tammy M. Weckwerth
Earth Observing Laboratory
National Center for Atmospheric Research
Boulder, USA
tammy@ucar.edu

Manfred Wendisch
Physics and Earth Sciences
University of Leipzig
Leipzig, Germany
m.wendisch@uni-leipzig.de

Mark Wenig
Department of Physics, Meteorological Institute Munich
Ludwig-Maximilians-University Munich
Munich, Germany
mark.wenig@lmu.de

Lisa K. Whalley
School of Chemistry
National Centre for Atmospheric Science, University of Leeds
Leeds, UK
l.k.whalley@leeds.ac.uk

Bodo Wichura
Climate and Environment Consultancy, Regional Office Potsdam
German Meteorological Service (DWD)
Potsdam, Germany
bodo.wichura@dwd.de

Stefan Wilbert
Institut für Solarforschung
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)
Almeria, Spain
stefan.wilbert@dlr.de

Martin Wirth
Institut für Physik der Atmosphäre
Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR)
Weßling, Germany
martin.wirth@dlr.de

Devon E. Worth
Science and Technology Branch
Agriculture and Agri-Food Canada
Ottawa, Canada
devon.worth@canada.ca

Volker Wulfmeyer
Institute of Physics and Meteorology
University of Hohenheim
Stuttgart, Germany
volker.wulfmeyer@uni-hohenheim.de

Astrid A. Ziemann
Chair of Meteorology
Technische Universität Dresden
Tharandt, Germany
astrid.ziemann@tu-dresden.de

Mark A. Zondlo
Civil and Environmental Engineering
Princeton University
Princeton, USA
mzondlo@princeton.edu

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