Climate and Weather of the Sun-Earth System (CAWSES)

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Franz-Josef Lübken

Editor

Climate and Weather of the Sun-Earth System (CAWSES)

Highlights from a Priority Program

Springer

Editor

Franz-Josef Lübken
Leibniz Institute of Atmospheric Physics
Rostock University
Kühlungsborn, Germany

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Foreword

The Sun, combined with the Earth's orbit, has always governed the activities of humanity on timescales from the changing seasons to glacial cycles. Changes in climate can be driven by alterations of the total solar irradiance (TSI) but recent evidence from satellites shows only modest changes in TSI which has only a minimal impact on the current changes that are being observed in the climate system. However the solar insolation at ultra-violet and extreme ultra-violet wavelengths changes from $\sim 7\%$ to more than 100% over a solar cycle and hence can result in major changes in the middle and upper atmospheres. For example, weaker westerly winds at the Earth's surface are observed in winters at sunspot minimum, and at sunspot maximum the temperature of the thermosphere is about 400 K greater than at sunspot minimum and the winds are about twice as strong.

Energetic particles from the Sun can change the climate system too. Observations of surface air temperatures, derived from climate re-analysis data, show differences between periods when there are significant space weather events compared to those periods when events are absent [Seppälä *et al.*, 2009]. Differences can be as large as $\sim 4\text{ K}$ with areas of warming and cooling approximately the same suggesting a redistribution of energy. However, the mechanism by which these changes occur is not known.

As changes in the Earth's atmosphere occur, whether due to changes of solar origin or in response to enhanced green house gas concentrations, the propagation and dissipation of gravity and planetary waves, and tides is altered. Clouds, whether they occur in the troposphere, stratosphere and mesosphere have a marked impact on the atmosphere. Thus, changes can occur on all spatial and temporal scales and both within and between different levels of the atmosphere caused by solar variations.

Addressing the Sun-Earth connections is both an essential and urgent issue. To understand both the natural variability of the climate system and those caused by humanity is essential for the prediction of future climate scenarios that have greater confidence. Therefore it is timely for the international community to have a focused scientific effort to address these critical issues.

Research over previous decades has provided solid explanations of many of the individual processes that are involved in the coupling of the Sun to the Earth environment but to make real progress at these scientific frontiers a system-level approach is now required, and indeed possible for the first time. The necessary science infrastructure has developed to a point where it is possible to address these topics. The worldwide research community now has access to international data sets from every critical region in the space environment, a highly-distributed, ground-based network of sensor, virtual observatories, advanced computational and visualisation facilities, and sophisticated Sun-to-Earth community models.

But the availability of data and models is not enough; an operating framework is also required and this has been provided by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). It was established as an Inter-Union Commission of International Council of Science (ICSU) in 1966 with the aim to promote and organise international interdisciplinary programmes of limited duration in solar-terrestrial physics. In 2004 SCOSTEP began the Climate and Weather of the Sun-Earth System program—CAWSES—with the specific objective to enhance understanding of the space environment and its impact on space weather and the climate. CAWSES made very substantial progress since its inception not only in pushing back the frontiers of knowledge but also in building science capacity in developing countries. It held the first virtual conference which had 270 participants. After five years, it was recognised that there was much still to be achieved and hence SCOSTEP endorsed CAWSES-II to run from 2009–2013. There was re-focusing of the working groups to reflect the evolution of science questions but the fundamental aim remained the same.

CAWSES and CAWSES-II only provide a scientific strategy and framework that gives focus for the development of relevant science activities. For such international initiatives to be successful the engagement of scientists across many disciplines in many countries is essential. It needs passionate scientific leadership, and champions who can persuade funding organisations to support the research. Funding agencies also have to be willing to take initiatives, and sometimes risks. The Deutsche Forschungsgemeinschaft (DFG) German Research Foundation recognised the importance of Sun-Earth connection science and created a German CAWSES Priority Programme. The Programme, very ably led by Prof. Dr. Franz-Josef Lübken, has explored many aspects of Sun-climate links as is amply demonstrated by the comprehensive and illuminating chapters in this book stretching from fundamental solar

physics through to the surface of the planet. There is an excellent blend of theory, observation and modelling. The Programme has also been very successful in educational terms giving many opportunities for early career scientists. We commend both the German CAWSES Priority Programme and the book—both are truly excellent exemplars for the research community.

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Chairs of CAWSES

Alan Rodger and Susan Avery

Preface

The Sun is the most important external driver of climate. Although the total solar irradiance (TSI) fluctuates by less than 0.1 % during a solar cycle, the solar impact on the terrestrial atmosphere can be significant, in particular in the upper atmosphere where the highly variable energetic part of the solar spectrum is absorbed. TSI variations on centennial time scales are of similar magnitude. Unfortunately, the scientific understanding of the variation of solar radiation (and its spectral components) and its impact on the atmosphere is rather limited. This concerns the direct modification of composition by solar radiation, but even more so various coupling mechanisms. For example, photochemically active gases are generated in the upper atmosphere, propagate to lower layers where they substantially alter the composition, e.g., the abundance of ozone. Planetary waves, gravity waves, and tides are excited in the atmosphere and propagate over large distances. They transport trace gases, energy, and momentum. Although these waves are most pronounced in the middle atmosphere, they may modify the background circulation in the entire atmosphere, even in the troposphere. As can be seen in various chapters in this book, major progress has been achieved in our understanding of solar radiation, its impact on the atmosphere, and coupling mechanisms within the atmosphere. Still, various uncertainties exist. For example, the observed solar signal in some parts of the middle atmosphere is larger than can be explained by models.

The purpose of this book is to summarise the scientific results related to a major research program of the international SCOSTEP organisation (Scientific Committee on Solar-Terrestrial Physics) called CAWSES (Climate And Weather of the Sun Earth System). The German Research Foundation (Deutsche Forschungsgemeinschaft, DFG) ran a priority program ('Schwerpunktprogramm', SPP) from 2005 to 2011 focusing on several important science topics from CAWSES. The aim of the CAWSES SPP is a better understanding of the influence of the Sun on the terrestrial atmosphere and the physical/chemical processes involved in various coupling mechanisms within the atmosphere. The DFG spent approximately 10 Million Euro for a total of 25–30 institutes. Most of the financial support from DFG was used for postdoctoral and PhD student positions. In 31 chapters, this book presents the scientific summaries from 28 projects supported under a total of 93 individual

grants. International cooperation was strongly encouraged and supported by funds for travel, etc. At each stage of the proposals, an international team of reviewers assisted the DFG in their selections. Several hundred papers were published in international peer reviewed journals within the priority program.

The book is structured in six parts, namely i) solar radiation, heliosphere, and galactic cosmic rays (Chaps. 2 to 6), ii) solar influence on trace gases (Chaps. 7 to 10), iii) thermosphere, energetic particles, and ionisation (Chaps. 11 to 17), iv) mesospheric ice clouds (Chaps. 18–20), v) gravity waves, planetary waves, and tides (Chaps 21 to 28), and vi) large-scale coupling (Chaps. 29 to 32). The evolution of solar radiation, its effect on galactic cosmic rays (GCR), and their potential impact on cloud droplets in the troposphere are studied in detail. Some chapters concentrate on the direct effect of solar radiation on trace gases, mainly on ozone and water vapour in the stratosphere and mesosphere. Precipitating particles of solar or geomagnetic origin modify the upper atmosphere directly. They also produce photochemically active species which can be transported downward and significantly affect the mesosphere and upper stratosphere. This aspect is studied in several chapters. Results on short and long-term variations of mesospheric ice clouds, as well as related microphysical aspects are presented. Planetary waves, gravity waves, and tides play a key role in distributing and modifying a signal being imposed somewhere in the atmosphere by, for example, the solar cycle. Physical details of this process and implications of wave morphology for the entire atmosphere, from the thermosphere to the troposphere, are presented in several chapters. Finally, results on global aspects of the solar cycle, long-term variations, and comparison with anthropogenic climate change are covered.

This book addresses researchers and students who are interested in actual results on solar cycle and long term variations in the atmosphere. The chapters are written by lead scientists from nearly all major German research institutions where the terrestrial atmosphere is investigated. A brief introduction is provided at the beginning of each chapter to familiarise a broader community with the scientific background. Each chapter was subject to an international peer review process to ensure high quality.

In the name of the German CAWSES community I thank the German Research Foundation for funding the CAWSES priority program. We appreciated the constructive and stimulating support from the reviewers, some of whom accompanied our program for the entire six years. As speaker of this program I would like to express my appreciation for all the activities, excitement, and success being created in various groups. Perhaps most important, many students were involved and contributed to the enthusiasm when working on a wide range of scientific topics of solar-terrestrial physics. I thank Dr. Norbert Engler and Monika Rosenthal for their excellent assistance when compiling this book.

Kühlungsborn
February 2012

Franz-Josef Lübken

Contents

1	Scientific Summary of the German CAWSES Priority Program . . .	1
	Franz-Josef Lübken	
2	Models of Solar Total and Spectral Irradiance Variability of Relevance for Climate Studies	19
	Natalie A. Krivova and Sami K. Solanki	
3	Investigation of Solar Irradiance Variations and Their Impact on Middle Atmospheric Ozone	39
	Mark Weber, Joseph Pagaran, Sebastian Dikty, Christian von Savigny, John P. Burrows, Matt DeLand, Linton E. Floyd, Jerry W. Harder, Martin G. Mlynczak, and Hauke Schmidt	
4	Solar Activity, the Heliosphere, Cosmic Rays and Their Impact on the Earth’s Atmosphere	55
	Horst Fichtner, Bernd Heber, Klaudia Herbst, Andreas Kopp, and Klaus Scherer	
5	Do Galactic Cosmic Rays Impact the Cirrus Cloud Cover?	79
	Susanne Rohs, Reinhold Spang, Lars Hoffmann, Franz Rohrer, and Cornelius Schiller	
6	Laboratory Experiments on the Microphysics of Electrified Cloud Droplets	89
	Daniel Rzesanke, Denis Duft, and Thomas Leisner	
7	Investigations of the Solar Influence on Middle Atmospheric Water Vapour and Ozone During the Last Solar Cycle—Analysis of the MPS Data Set	109
	Paul Hartogh, Christopher Jarchow, and Kristoffer Hallgren	

8	Influence of Solar Radiation on the Diurnal and Seasonal Variability of O₃ and H₂O in the Stratosphere and Lower Mesosphere, Based on Continuous Observations in the Tropics and the High Arctic	125
	Mathias Palm, Sven H.W. Golchert, Miriam Sinnhuber, Gerd Hochschild, and Justus Notholt	
9	Data Assimilation and Model Calculations to Study Chemistry Climate Interactions in the Stratosphere	149
	Björn-Martin Sinnhuber, Gregor Kieseewetter, John P. Burrows, and Ulrike Langematz	
10	The Response of Atomic Hydrogen to Solar Radiation Changes . . .	171
	Martin Kaufmann, Manfred Ern, Catrin Lehmann, and Martin Riese	
11	High-Latitude Thermospheric Density and Wind Dependence on Solar and Magnetic Activity	189
	Hermann Lühr and Stefanie Marker	
12	Global Sporadic E Layer Characteristics Obtained from GPS Radio Occultation Measurements	207
	Christina Arras, Jens Wickert, Christoph Jacobi, Georg Beyerle, Stefan Heise, and Torsten Schmidt	
13	Atmospheric Ionization Due to Precipitating Charged Particles . . .	223
	Jan Maik Wissing, Jan Philipp Bornebusch, and May-Britt Kallenrode	
14	EISCAT's Contributions to High Latitude Ionosphere and Atmosphere Science Within CAWSES in Germany	235
	Jürgen Röttger and Norbert Engler	
15	The Influence of Energetic Particles on the Chemistry of the Middle Atmosphere	247
	Thomas Reddmann, Bernd Funke, Paul Konopka, Gabriele Stiller, Stefan Versick, and Bärbel Vogel	
16	The Impact of Energetic Particle Precipitation on the Chemical Composition of the Middle Atmosphere: Measurements and Model Predictions	275
	Miriam Sinnhuber, Nadine Wieters, and Holger Winkler	
17	Simulation of Particle Precipitation Effects on the Atmosphere with the MESSy Model System	301
	Andreas J.G. Baumgaertner, Patrick Jöckel, Alan D. Aylward, and Matthew J. Harris	
18	Solar Variability and Trend Effects in Mesospheric Ice Layers	317
	Franz-Josef Lübken, Uwe Berger, Johannes Kiliani, Gerd Baumgarten, and Jens Fiedler	

19	Charged Aerosol Effects on the Scattering of Radar Waves from the D-Region	339
	Markus Rapp, Irina Strelnikova, Qiang Li, Norbert Engler, and Georg Teiser	
20	Impact of Short-Term Solar Variability on the Polar Summer Mesopause and Noctilucent Clouds	365
	Christian von Savigny, Charles Robert, Nabiz Rahpoe, Holger Winkler, Erich Becker, Heinrich Bovensmann, John P. Burrows, and Matthew T. DeLand	
21	Observations and Ray Tracing of Gravity Waves: Implications for Global Modeling	383
	Manfred Ern, Christina Arras, Antonia Faber, Kristina Fröhlich, Christoph Jacobi, Silvio Kalisch, Marc Krebsbach, Peter Preusse, Torsten Schmidt, and Jens Wickert	
22	Atmospheric Coupling by Gravity Waves: Climatology of Gravity Wave Activity, Mesospheric Turbulence and Their Relations to Solar Activity	409
	Werner Singer, Peter Hoffmann, G. Kishore Kumar, Nicholas J. Mitchell, and Vivien Matthias	
23	Infra-red Radiative Cooling/Heating of the Mesosphere and Lower Thermosphere Due to the Small-Scale Temperature Fluctuations Associated with Gravity Waves	429
	Alexander A. Kutepov, Artem G. Feofilov, Alexander S. Medvedev, Uwe Berger, Martin Kaufmann, and Adalbert W.A. Pauldrach	
24	The Influence of Zonally Asymmetric Stratospheric Ozone on the Coupling of Atmospheric Layers	443
	Axel Gabriel, Ines Höschel, Dieter H.W. Peters, Ingo Kirchner, and Hans-F. Graf	
25	Extending the Parameterization of Gravity Waves into the Thermosphere and Modeling Their Effects	467
	Erdal Yiğit and Alexander S. Medvedev	
26	The Geospace Response to Nonmigrating Tides	481
	Kathrin Häusler, Jens Oberheide, Hermann Lühr, and Ralf Koppmann	
27	Solar Diurnal Tides in the Middle Atmosphere: Interactions with the Zonal-Mean Flow, Planetary Waves and Gravity Waves	507
	Ulrich Achatz, Fabian Senf, and Norbert Grieger	
28	Short Period Dynamics in the Mesosphere: Morphology, Trends, and the General Circulation	517
	Dirk Offermann and Ralf Koppmann	

29	Solar Effects on Chemistry and Climate Including Ocean Interactions	541
	Ulrike Langematz, Anne Kubin, Christoph Brühl, Andreas J.G. Baumgaertner, Ulrich Cubasch, and Thomas Spanghel	
30	Interannual Variability and Trends in the Stratosphere	573
	Karin Labitzke and Markus Kunze	
31	The Atmospheric Response to Solar Variability: Simulations with a General Circulation and Chemistry Model for the Entire Atmosphere	585
	Hauke Schmidt, Jens Kieser, Stergios Misios, and Aleksandr N. Gruzdev	
32	Long-Term Behaviour of Stratospheric Transport and Mean Age as Observed from Balloon and Satellite Platforms	605
	Gabriele Stiller, Andreas Engel, Harald Bönisch, Norbert Glatthor, Florian Haenel, Andrea Linden, Tanja Möbius, and Thomas von Clarmann	
	Acronyms and Abbreviations	625
	Index	631

List of Contributors

Ulrich Achatz Institute for Atmospheric and Environmental Sciences, Goethe University, Frankfurt (Main), Germany

Christina Arras Dept. Geodesy and Remote Sensing, German Research Centre for Geosciences GFZ, Potsdam, Potsdam, Germany; GFZ German Research Centre for Geosciences, Potsdam, Germany

Alan D. Aylward Atmospheric Physics Laboratory, University College London, London, UK

Andreas J.G. Baumgaertner Max Planck Institute for Chemistry, Mainz, Germany; Deutsches Zentrum für Luft-und Raumfahrt (DLR), Project Management Agency, Bonn, Germany

Gerd Baumgarten Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Erich Becker Institute of Atmospheric Physics, Kühlungsborn, Germany

Uwe Berger Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Georg Beyerle GFZ German Research Centre for Geosciences, Potsdam, Germany

Jan Philipp Bornebusch University of Osnabrück, Osnabrück, Germany

Heinrich Bovensmann Institute of Environmental Physics, University of Bremen, Bremen, Germany

Harald Bönisch Experimental Atmospheric Research Institute for Atmospheric and Environmental Sciences, Goethe-University Frankfurt, Frankfurt am Main, Germany

Christoph Brühl Max-Planck-Institut für Chemie, Mainz, Germany

John P. Burrows Institute of Environmental Physics, University of Bremen FB1, Bremen, Germany

Ulrich Cubasch Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany

Matt DeLand Science System and Applications, Inc (SSAI), Lanham, MD, USA

Matthew T. DeLand Science Systems and Applications, Inc., Lanham, MD, USA

Sebastian Dikty Institute of Environmental Physics, University of Bremen FB1, Bremen, Germany

Denis Duft Institute for Meteorology and Climate Research – Atmospheric Aerosol Research (IMK-AAF), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Andreas Engel Experimental Atmospheric Research Institute for Atmospheric and Environmental Sciences, Goethe-University Frankfurt, Frankfurt am Main, Germany

Norbert Engler Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Manfred Ern Institute of Energy and Climate Research (IEK-7), Forschungszentrum Jülich, Jülich, Germany; Institute for Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany

Antonia Faber Dept. Geodesy and Remote Sensing, German Research Centre for Geosciences GFZ, Potsdam, Potsdam, Germany

Artem G. Feofilov Laboratory of Dynamical Meteorology, École Polytechnique, Palaiseau Cedex, France

Horst Fichtner Theoretische Physik IV, Ruhr-Universität Bochum, Bochum, Germany

Jens Fiedler Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Linton E. Floyd Interferometrics Inc., Herndon, Virginia, VA, USA

Kristina Fröhlich Dept. Climate and Environment, Deutscher Wetterdienst, Offenbach, Germany

Bernd Funke Instituto de Astrofísica de Andalucía (CSIC), Granada, Spain

Axel Gabriel Leibniz-Institute of Atmospheric Physics at the University Rostock, Kühlungsborn, Germany

Norbert Glatthor Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Eggenstein-Leopoldshafen, Germany

Sven H.W. Golchert Institut für Klimaforschung, KIT Karlsruhe, Eggenstein-Leopoldshafen, Germany

Hans-F. Graf Centre for Atmospheric Science, Cambridge University, Cambridge CB2 3EN, UK

Norbert Grieger Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Aleksandr N. Gruzdev A. M. Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences, Moscow, Russia

Florian Haenel Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Eggenstein-Leopoldshafen, Germany

Kristoffer Hallgren Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany

Jerry W. Harder Laboratory for Atmospheric and Space Physics (LASP), University of Colorado, Boulder, CO, USA

Matthew J. Harris Atmospheric Physics Laboratory, University College London, London, UK

Paul Hartogh Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany

Kathrin Häusler GFZ German Research Centre for Geosciences, Potsdam, Germany; High Altitude Observatory, National Center for Atmospheric Research, Boulder, CO, USA

Bernd Heber Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

Stefan Heise GFZ German Research Centre for Geosciences, Potsdam, Germany

Klaudia Herbst Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

Gerd Hochschild Institut für Klimaforschung, KIT Karlsruhe, Eggenstein-Leopoldshafen, Germany

Lars Hoffmann IEK-7, Forschungszentrum Jülich GmbH, Jülich, Germany

Peter Hoffmann Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Ines Höschel Institut für Meteorologie, Berlin, Germany

Christoph Jacobi Institute for Meteorology, University of Leipzig, Leipzig, Germany

Christopher Jarchow Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany

Patrick Jöckel Max Planck Institute for Chemistry, Mainz, Germany; Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft-und Raumfahrt (DLR), Weßling, Germany

Silvio Kalisch Institute of Energy and Climate Research (IEK-7), Forschungszentrum Jülich, Jülich, Germany

May-Britt Kallenrode University of Osnabrück, Osnabrück, Germany

Martin Kaufmann Institute for Chemistry and Dynamics of Geosphere, Forschungszentrum Jülich GmbH, Jülich, Germany; Institute for Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany

Jens Kieser Max Planck Institute for Meteorology, Hamburg, Germany

Gregor Kieseewetter Institute of Environmental Physics, University of Bremen, Bremen, Germany

Johannes Kiliani Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Ingo Kirchner Institut für Meteorologie, Berlin, Germany

G. Kishore Kumar Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Paul Konopka Institute for Energy and Climate Research – Stratosphere (IEK-7) Forschungszentrum Jülich GmbH (FZJ), Jülich, Germany

Andreas Kopp Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Kiel, Germany

Ralf Koppmann Faculty of Mathematics and Natural Sciences, Physics Department, University of Wuppertal, Wuppertal, Germany; Physics Department, University of Wuppertal, Wuppertal, Germany

Marc Krebsbach Physics Department, University of Wuppertal, Wuppertal, Germany

Natalie A. Krivova Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany

Anne Kubin Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany

Markus Kunze Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany

Alexander A. Kutepov Department of Physics, The Catholic University of America/NASA Goddard Space Flight Center, Greenbelt, MD, USA

Karin Labitzke Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany

Ulrike Langematz Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany

Catrin Lehmann Institute for Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany

Thomas Leisner Institute for Meteorology and Climate Research – Atmospheric Aerosol Research (IMK-AAF), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Qiang Li Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Andrea Linden Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Eggenstein-Leopoldshafen, Germany

Franz-Josef Lübken Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Hermann Lühr GFZ German Research Centre for Geosciences, Potsdam, Germany

Stefanie Marker ILS Kraftfahrzeuge, Technische Universität Berlin, Berlin, Germany

Vivien Matthias Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Alexander S. Medvedev Max Planck Institute for Solar System Research, Katlenburg-Lindau, Germany

Stergios Misios Max Planck Institute for Meteorology, Hamburg, Germany

Nicholas J. Mitchell Centre for Space, Atmospheric and Oceanic Science, Department of Electronic and Electrical Engineering, University of Bath, Bath, UK

Martin G. Mlynczak NASA Langley Research Center, Hampton, VA, USA

Tanja Möbius Experimental Atmospheric Research Institute for Atmospheric and Environmental Sciences, Goethe-University Frankfurt, Frankfurt am Main, Germany

Justus Notholt Institut für Umweltphysik, Universität Bremen, Bremen, Germany

Jens Oberheide Department of Physics and Astronomy, Clemson University, Clemson, SC, USA

Dirk Offermann Faculty of Mathematics and Natural Sciences, Physics Department, University of Wuppertal, Wuppertal, Germany

Joseph Pagarán Institute of Environmental Physics, University of Bremen FB1, Bremen, Germany

Mathias Palm Institut für Umweltphysik, Universität Bremen, Bremen, Germany

Adalbert W.A. Pauldrach University Observatory Munich/Wendelstein Observatory, Munich, Germany

Dieter H.W. Peters Leibniz-Institute of Atmospheric Physics at the University Rostock, Kühlungsborn, Germany

Peter Preusse Institute of Energy and Climate Research (IEK-7), Forschungszentrum Jülich, Jülich, Germany

Nabiz Rahpoe Institute of Environmental Physics, University of Bremen, Bremen, Germany

Markus Rapp Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany; Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institute of Atmospheric Physics, Wessling, Germany

Thomas Reddmann Karlsruhe Institute of Technology (KIT), Inst. for Meteorology and Climate Research, Karlsruhe, Germany

Martin Riese Institute for Energy and Climate Research – Stratosphere (IEK-7), Jülich, Germany

Charles Robert Belgium Institute of Space Aeronomy (BIRA), Brussels, Belgium

Franz Rohrer IEK-8, Forschungszentrum Jülich GmbH, Jülich, Germany

Susanne Rohs IEK-7, Forschungszentrum Jülich GmbH, Jülich, Germany

Jürgen Röttger Max-Planck-Institute of Solar System Research, Katlenburg-Lindau, Germany

Daniel Rzesanke Institute for Meteorology and Climate Research – Atmospheric Aerosol Research (IMK-AAF), Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

Klaus Scherer Theoretische Physik IV, Ruhr-Universität Bochum, Bochum, Germany

Cornelius Schiller IEK-7, Forschungszentrum Jülich GmbH, Jülich, Germany

Hauke Schmidt Max Planck Institute for Meteorology, Hamburg, Germany

Torsten Schmidt Dept. Geodesy and Remote Sensing, German Research Centre for Geosciences GFZ, Potsdam, Potsdam, Germany

Fabian Senf Leibniz-Institute of Atmospheric Physics, Kühlungsborn, Germany

Werner Singer Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Björn-Martin Sinnhuber Institute of Environmental Physics, University of Bremen, Bremen, Germany; Now at Karlsruhe Institute of Technology, Karlsruhe, Germany

Miriam Sinnhuber Institut für Klimaforschung, KIT Karlsruhe, Eggenstein-Leopoldshafen, Germany; Institute of Environmental Physics, University of Bremen, Bremen, Germany; Institute for Meteorology and Climate Research, Karlsruhe Institute of Technology, Leopoldshafen, Germany

Sami K. Solanki Max-Planck-Institut für Sonnensystemforschung, Katlenburg-Lindau, Germany; School of Space Research, Kyung Hee University, Gyeonggi, Yongin, Korea

Reinhold Spang IEK-7, Forschungszentrum Jülich GmbH, Jülich, Germany

Thomas Spangehl Institut für Meteorologie, Freie Universität Berlin, Berlin, Germany; Deutscher Wetterdienst, Offenbach am Main, Germany

Gabriele Stiller Karlsruhe Institute of Technology (KIT), Inst. for Meteorology and Climate Research, Karlsruhe, Germany; Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Eggenstein-Leopoldshafen, Germany

Irina Strelnikova Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Georg Teiser Leibniz-Institute of Atmospheric Physics at the Rostock University, Kühlungsborn, Germany

Stefan Versick Karlsruhe Institute of Technology (KIT), Inst. for Meteorology and Climate Research, Karlsruhe, Germany

Bärbel Vogel Institute for Energy and Climate Research – Stratosphere (IEK-7) Forschungszentrum Jülich GmbH (FZJ), Jülich, Germany

Thomas von Clarmann Karlsruhe Institute of Technology, Institute for Meteorology and Climate Research, Eggenstein-Leopoldshafen, Germany

Christian von Savigny Institute of Environmental Physics, University of Bremen FB1, Bremen, Germany; Institute of Physics, Ernst-Moritz-Arndt-University of Greifswald, Greifswald, Germany

Mark Weber Institute of Environmental Physics, University of Bremen FB1, Bremen, Germany

Jens Wickert Dept. Geodesy and Remote Sensing, German Research Centre for Geosciences GFZ, Potsdam, Potsdam, Germany

Nadine Wieters Institute of Environmental Physics, University of Bremen, Bremen, Germany

Holger Winkler Institute of Environmental Physics, University of Bremen, Bremen, Germany

Jan Maik Wissing University of Osnabrück, Osnabrück, Germany

Erdal Yiğit Department of Atmospheric Oceanic and Space Sciences, Ann Arbor, MI, USA; Space Sciences Laboratory, UC Berkeley, Berkeley, CA, USA