Proposal to ISSI: International Team in Earth Sciences

Polar Stratospheric Cloud initiative (PSCi) Workshops

Abstract

After nearly three decades of research, the role of polar stratospheric clouds (PSCs) in stratospheric ozone depletion is generally well established. However, important questions remain unanswered that limit our understanding of PSC processes and how to accurately represent them in global models, calling into question our prognostic capabilities for future ozone loss in a changing climate. A more complete picture of PSC morphology and composition on polar vortex-wide scales is emerging from a suite of recent satellite missions: the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on Envisat (2002-2012), the Microwave Limb Sounder (MLS) on Aura (2004-present), and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO (2006-present). These datasets have motivated numerous PSC research activities that both extend and challenge our present knowledge of PSC processes and modeling capabilities. In this project, key questions related to PSC formation and evolution and their representation in global models will be addressed through the following main objectives: identify the key PSC parameters which are required by global models; compare remote and in situ datasets to identify their strengths and limitations; define a methodology to obtain the key PSC properties required by models from the observational datasets; synthesize the new satellite measurements and earlier datasets into a state of the art PSC climatology; and identify remaining open science questions. These activities will ultimately lead to improved representation of PSC processes in global climate models and to the development of a database against which existing and future models may be tested. To achieve these goals, we will bring together an international team of key scientists representing satellite, ground-based, balloon, and aircraft measurements, as well as theoreticians and modelers, in a series of focused meetings to be held at ISSI. The ultimate outcomes will include a journal paper or SPARC (Stratosphere-troposphere Processes and their Role in Climate, a core project of the World Climate Research Program) report describing the new PSC reference climatology and a journal review paper on the overall state of PSC science.

Scientific rationale

The essential role of polar stratospheric clouds (PSCs) in the depletion of stratospheric ozone has been well established [Solomon, 1999]. Heterogeneous reactions on PSCs convert stable chlorine reservoirs of HCl and $ClONO_2$ to chlorine radicals that destroy ozone catalytically. Rates of these heterogeneous reactions depend on particle surface area and composition, which includes liquid binary H_2SO_4/H_2O droplets (background stratospheric aerosol); liquid ternary $HNO_3/H_2SO_4/H_2O$ droplets (STS); solid nitric acid trihydrate (NAT) particles; and H_2O ice particles. PSCs also affect ozone chemistry through the removal of HNO_3 from the polar stratosphere (denitrification) via the formation and sedimentation of large NAT PSC particles. Denitrification enhances ozone depletion by delaying the reformation of the benign chlorine reservoirs.

In spite of this clear understanding of the role of PSCs in ozone loss and nearly three decades of research, the details of how NAT particles form, grow, and sediment, leading to the denitrification required for sustained ozone loss, are still not well understood. Furthermore, the extent of chlorine activation on cold background stratospheric aerosol, before PSCs form, is uncertain. These uncertainties significantly limit our ability to represent PSC processes accurately in global models and constrain our prognostic capabilities concerning future ozone loss in a changing climate. This is of particular concern in the Arctic, where winter temperatures hover near the PSC threshold, and, hence, future stratospheric cooling could lead to enhanced stratospheric cloud formation and concomitant greater ozone losses.

A limiting factor in advancing our understanding of PSC processes has been the relative sparseness of PSC observations. Since the discovery of polar ozone loss, PSC observations have consisted primarily of long-term, but spatially limited remote measurements from ground-based stations and solar occultation satellites, interspersed with in situ and remote measurements from occasional intensive, but still localized field campaigns. The observational database has expanded greatly over the past decade with the advent of three satellite missions with extensive polar measurement coverage: the Michelson Interferometer for Passive Atmospheric Sounding (MIPAS) on Envisat (2002-2012), the Microwave Limb Sounder (MLS) on Aura (2004-present), and the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) on CALIPSO (2006-present). These datasets, which provide measurements of PSC occurrence and composition and relevant gas species on unprecedented polar vortex-wide scales, have ushered in a new era in PSC research with numerous opportunities for utilizing these satellite datasets to both extend and challenge present knowledge of PSC processes and modeling capabilities.

The time is right for utilizing these new observations to test PSC modeling and to reexamine older measurements in the context of today's knowledge. In this project, key questions related to PSC formation and evolution and their representation in global models will be addressed through the following main objectives: identify the key PSC characteristics which are required by global models and can be inferred from measurements; define methods to obtain the key PSC properties required by models from the observational datasets; compare remote and in situ datasets to identify their strengths and limitations; synthesize the new satellite datasets with earlier datasets into a state of the art PSC data record and climatology; and identify remaining open science questions. These activities will ultimately lead to improved representation of PSC processes in global climate models and to the development of a database against which future models may be tested. To achieve these goals, we will bring together an international team of key scientists representing satellite, ground-based, balloon, and aircraft measurements, as well as theoreticians and modelers, in a series of focused meetings to be held at ISSI. The ultimate outcomes will include a journal paper or SPARC report describing the new PSC climatology and a journal review paper on the overall state of PSC science.

In January 2015 a new Polar Stratospheric Cloud initiative (PSCi) was started within SPARC and was approved by the SPARC Scientific Steering Group. The work carried out during the proposed project will be an integral part of the PSCi.

Scientific objectives

Task 1: Satellite data

The first task is assess the relative strengths and limitations of the MIPAS, MLS, and CALIOP satellite instruments, which employ totally different measurement approaches to retrieve information on PSCs. MIPAS is a limb-viewing Fourier transform spectrometer that observes mid-infrared radiation emitted and scattered by PSCs [Höpfner et al., 2002] with spatial sampling scales of approximately 1.5-3 km vertical x 400-500 km along track (depending on measurement mode). Spectral signatures of HNO_3 and/or H_2O allow unambiguous detection of the presence of NAT and ice [Höpfner et al., 2009]. Aura MLS observes limb thermal emission at millimeter and sub-millimeter wavelengths providing measurements of the gas phase abundance of the relevant PSC condensables HNO_3 and H_2O [Waters et al., 2006] with spatial sampling similar to MIPAS (approximately 3-5 km vertical x 200-500 km along track). The MLS observations of the HNO_3

and H_2O gas phase abundances, coupled with ambient temperatures and temperature histories, provide a means to investigate PSC particle formation mechanisms with the particle types identified by CALIOP/MIPAS as mixtures of NAT/STS, Ice/STS, or STS alone [Lambert et al., 2012]. CALIOP is a dual wavelength (532 and 1064 nm), polarization sensitive lidar that measures backscatter from cloud and aerosol particles in the atmosphere [Winker et al., 2009]. PSCs are identified through enhancements in lidar scattering ratio or perpendicular backscatter at 532 nm. Enhancements in perpendicular backscatter indicate the presence of non-spherical particles which in the case of PSCs are attributed to NAT or ice particles [Pitts et al., 2009; Pitts et al., 2013]. CALIOP PSC products are reported on a high resolution 180 m vertical by 5 km horizontal along track grid.

To assess the sensitivity of each measurement system to the presence of PSCs, we will identify a number of test cases where all three instruments are observing the same PSC field. Cases will be chosen to include PSCs of varying optical depth and composition. For each case, we will investigate how the inherent spatial resolution/viewing geometry of the individual instruments impacts the retrieved PSC information and comparisons between the instruments. We will also attempt to quantify the detection limits/sensitivities of each instrument in terms of particle characteristics (e.g., NAT particle number and size, total volume, etc.). This task will be a priority for the first meeting.

Task 2: Ground-based lidar and in situ particle data
Other contemporary data sets on PSCs will be used to assess the quality and information content of the spaceborne PSC measurements. Long-term data records exist from ground-based lidars in both the Arctic (e.g., Kiruna, Ny Ålesund) and Antarctic (South Pole, McMurdo, Dumont d'Urville, Davis). These ground-based lidars measure the backscatter from PSC particles with much lower noise than spaceborne lidars, but their data are limited to single locations. Another valuable data resource is in situ PSC particle size distribution measurements from balloon and aircraft flights of opportunity. These measured size distributions can be used to simulate the signals being measured by the satellite instruments to test the relative sensitivity of the satellite measurements to the presence of a sparse population of large NAT particles and to test methods of inverting the satellite measurements to particle surface area, which is required by global models that include the impact of PSCs on ozone. Providing a framework for utilizing the remote spaceborne and ground-based measurements to provide more relevant physical properties of PSCs will expand the utility of the modern and historical datasets.

Task 3: PSC reference climatology
One of the primary goals of this project is to produce a state of the art PSC reference climatology for use by global models. The climatology will be a result of the synthesis of all the PSC datasets discussed above. We will identify the key PSC characteristics required by global models that can be inferred from the measurements. These may include particle composition/phase and surface area. The resultant climatology will capture seasonal variations, spatial variations, and hemispheric differences.

Task 4: Recent research developments/remaining open questions
The goal of this task is to review and document other recent research activities related to PSCs and identify significant findings and remaining open science questions. Together with the outputs from Tasks 1-3, this will form the backbone of a comprehensive review paper on the current state of PSC science.

Timeliness

The MIPAS, Aura MLS, and CALIPSO missions comprise what could be called the 'golden age' for PSC observations. In combination, this suite of measurements represents the most comprehensive PSC observational data record in existence and will serve as the foundation for our state of the art PSC reference climatology. In addition, recent studies utilizing these datasets have shed new light on NAT formation mechanisms, which differ significantly from our previous understanding [Hoyle et al., 2013; Engel et al., 2013]. It is now time for the scientific community to synthesize all of these new findings and address our state of understanding through an international project under the auspices of PSCi.

Expected project outcome

- State of the art PSC reference climatology based on merged datasets
- High-profile scientific paper describing new state of the art PSC climatology
- High-profile review paper on overall state of PSC science.

List of confirmed team members

Our international team members are leading experts on satellite, ground-based, and in situ measurements of PSCs, Lagrangian measurement and modeling techniques, data analysis and global modeling. The expertise of the team members is complementary and aligned with the goals of the proposed project. The ISSI Young Scientist scheme is essential in enabling the participation of two excellent early career scientists in the field of PSC research: Dr. Ines Tritscher, Forschungszentrum Juelich, Germany and Dr. Sergej Molleker, Max Planck Institute for Chemistry, Germany. The team will be led by Dr. Michael Pitts.

Dr. Michael Pitts (USA, **team leader**, satellite)
Dr. Ines Tritscher (Germany, **young scientist**, theory and modeling)
Dr. Lamont Poole (USA, satellite)
Dr. Thomas Peter (Switzerland, theory and modeling)
Dr. Simon Alexander (Australia, theory and modeling)
Dr. Francesco Cairo (Italy, ground-based lidar and aircraft)
Dr. Terry Deshler (USA, in situ particle measurements, balloons)
Dr. Jens-Uwe Grooß (Germany, theory and modeling)
Dr. Michael Höpfner (Germany, satellite)
Dr. Alyn Lambert (USA, satellite)
Dr. Sergej Molleker (Germany, **young scientist**, in situ particle measurements)
Dr. Ross Salawitch (USA, theory and modeling)
Dr. Reinhold Spang (Germany, satellite)

What added value does ISSI provide for the implementation of the Team activity?

ISSI provides the unique opportunity to fund "international teams" around a multidisciplinary scientific project such as this, providing comfortable facilities where the team members can share their knowledge and work together. It would be difficult, if not impossible, to assemble this team through conventional funding mechanisms. Face-to-face meetings to discuss and interpret the satellite data sets are imperative for our project to succeed in a timely fashion. By facilitating these meetings, ISSI will help advance PSC science leading to improved representation of PSC processes in global climate models and, ultimately, improved predictions of ozone recovery.

Project schedule

We anticipate three one-week meetings in Bern with a schedule as follows:

Autumn 2015 **First meeting at ISSI**

- Quantify detection limits/sensitivities of satellite instruments
- Compare ground-based lidar and in situ data with satellite data
- Discuss key parameters to include in PSC climatology
- Discuss framework for PSC climatology
- Develop detailed outline of PSC climatology paper

Autumn/Winter 2015-2016 **Time between the meetings**

- Frequently Skype/video/teleconferences
- Implementation of the specific tasks the team members have agreed on
- Monitoring of progress by the team leader

Spring 2016 **Second meeting at ISSI**

- Review results and progress obtained since the first meeting
- Write draft of climatology paper
- Develop detailed outline of PSC review paper

Summer 2016 **Time between the meetings**

- Frequently Skype/video/teleconferences
- Implementation of the specific tasks the team members have agreed on
- Monitoring of progress by the team leader
- Submit climatology paper

Autumn/Winter 2016-2017 **Third meeting at ISSI**

- Write draft of review paper on state of PSC science

Spring 2017 **After the last meeting**

- Submit review paper on state of PSC science
- Submit final report to ISSI

Required facilities at ISSI

For all meetings at ISSI we will require a plenary room large enough to accommodate 14-16 people, and one smaller room for breakout group work. As scientific presentations will be one important part of the meetings, the plenary room needs to be equipped with whiteboard, a computer projector and a screen. Wireless internet connection will be needed for all participants to allow access to databases and electronically available literature. A copy machine, printer, and electric adaptors to the Swiss standard would also be helpful. Water/coffee/tea for refreshment during the meeting would be highly appreciated.

Required financial support

We request per diem (meals and lodging) for each of the 13 team members (which already includes two young scientists). Per diem will be needed for approximately 5 days for each participant for each of three meetings. We also request travel support for the team leader or a designated participant in need. If funding is not available to support the entire team for all three meetings, some members may be able to secure full or partial financial support for their participation from alternative sources.

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Appendix A: Contact Information for Confirmed Participants

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Appendix B: Short CVs of Team Members

Dr. Michael C. Pitts (Team Leader)

Education:

Ph.D.	Atmospheric Science	College of William and Mary	1999
M.S.	Atmospheric Science	Georgia Institute of Technology	1981
B.S.	Meteorology	Florida State University	1979

Professional Experience:

NASA Langley Research Center, Research Scientist, 1999 - Present
Science Applications International Corporation, Atmospheric Scientist, 1992 – 1999
Hughes STX Corporation, Atmospheric Scientist, 1982 – 1992

Summary of Relevant Research Experience:

Dr. Pitts' research is focused on analysis and interpretation of aerosol and cloud remote sensing data sets that are critical for assessing key climate change issues. Over the past two decades, he has made significant contributions to polar stratospheric cloud (PSC) research, including studies of their formation, distribution, and evolution. His early research collaboration with Dr. Lamont Poole led to the publication of the first comprehensive PSC climatology. As a member of the CALIPSO/CloudSat Science Team, his current research is focused on interpretation and analyses of CALIPSO PSC data. He has participated in numerous field campaigns including AASE, SOLVE-2, and RECONCILE which were focused on PSC process studies.

Honors/Awards: NASA Exceptional Achievement Medal, 2010

Selected Relevant Publications:

Dr. Pitts is the author or co-author of more than 45 formal publications and over 100 additional presentations and informal publications. Recent publications directly relevant to this proposal:

Pitts, M. C., L. W. Thomason, L. R. Poole, and D. W. Winker, Characterization of polar stratospheric clouds with spaceborne lidar: CALIPSO and the 2006 Antarctic season, *Atmos. Chem. Phys., 7,* 5207-5228, 2007.

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Pitts, M. C., L. R. Poole, A. Lambert, and L. W. Thomason, An assessment of CALIOP polar stratospheric cloud composition classification, *Atmos. Chem. Phys., 13*, 2975–2988, 2013.

Dr. Ines Tritscher (maiden name: Engel)

Young Scientist

Education:

Ph.D., Atmospheric Sciences, ETH Zurich, Switzerland, 22 August 2013
Diploma in Landscape Ecology at the University of Münster, Germany, 2009

Professional Experience:

Postdoctoral researcher at IEK-7, Forschungszentrum Jülich, 2013-present

Summary of Relevant Research Activities:

Dr. Ines Tritscher devoted her PhD to polar stratospheric clouds (PSCs) research through field and lab work and with a strong focus on data interpretation and modeling. Together with her colleagues at ETH Zurich, she demonstrated the importance of heterogeneous nucleation of solid PSC particles by detailed box modeling. Her ongoing postdoctoral research at the Forschungszentrum Jülich aims at improved PSC formation parameterizations within the Chemical Lagrangian Model of the Stratosphere (CLaMS) for global modeling studies. Dr. Tritscher is co-leader of an emerging PSC SPARC activity and contributor to Chapter 3 of the WMO Scientific Assessment of Ozone Depletion 2014.

Honors/Awards:

Atmospheric Chemistry and Physics (ACP) Award granted by the Atmospheric Chemistry and Physics Commission of the Swiss Academy of Sciences, 2013

Selected Relevant Publications:

Grooß, J.-U., **Engel, I.**, Borrmann, S., Frey, W., Günther, G., Hoyle, C. R., Kivi, R., Luo, B. P., Molleker, S., Peter, T., Pitts, M. C., Schlager, H., Stiller, G., Vömel, H., Walker, K. A., and Müller, R.: Nitric acid trihydrate nucleation and denitrification in the Arctic stratosphere, *Atmos. Chem. Phys.*, 14, 1055-1073, 2014.

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Dr. Lamont R. Poole

Education:

Ph. D., Atmospheric Sciences, University of Arizona, 1987
M. S., Civil, Mechanical, and Environmental Engineering, George Washington U., 1973
B. S., Aerospace Engineering (with High Honors), North Carolina State University, 1970

Professional Experience:

Senior Research Scientist, Science Systems & Applications, Incorporated, Hampton, VA, December 2006-present
Senior Atmospheric Scientist, Science Applications International Corporation, Hampton, VA, February 2005-November 2006
Senior Research Scientist/Supervisor, NASA Langley Research Center, 1988-2004
Research Scientist, NASA Langley Research Center, 1970-1988

Summary of Relevant Research Experience:

Dr. Poole's research has been focused for nearly three decades on the analysis and interpretation of aerosol and cloud data from spaceborne, airborne, and ground-based instruments. He is currently a co-investigator on the NASA CALIPSO/CloudSat science team. Dr. Poole has made a number of major contributions to polar stratospheric cloud (PSC) research, both in modeling and in remote sensing data analysis. He served as lead scientist on two Arctic PSC airborne lidar campaigns, and was a member of international science teams for the Airborne Antarctic Ozone Experiment, the Airborne Arctic Stratospheric Experiment, and the SAGE III Ozone Loss and Validation Experiments.

Honors/Awards:

NASA Exceptional Scientific Achievement Medal, 1996
NASA Langley H. J. E. Reid Award for outstanding scientific paper of the year, 1990

Selected Relevant Publications:

Dr. Poole is the author or co-author of 92 formal publications and over 150 additional presentations and informal publications. Recent publications directly relevant to this proposal:

Pitts, M. C., L. W. Thomason, L. R. Poole, and D. W. Winker, Characterization of polar stratospheric clouds with spaceborne lidar: CALIPSO and the 2006 Antarctic season, Atmos. Chem. Phys., 7, 5207-5228, 2007.

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Dr. Thomas Peter

Education:

- 1980 BSc in Physics and Mathematics, University of Marburg, Germany
- 1982 MSc studies in Physics, University of Maryland, USA
- 1985 MSc in Physics (summa cum laude), Techn. Univ. Munich, Germany
- 1988 PhD (magna cum laude), Max Planck Institute (MPI) for Quantum Optics

Professional Experience:

- 1988-1990 Scientific staff at MPI for Quantum Optics, Munich, Germany
- 1990-1994 Scientific staff at MPI for Chemistry, Mainz, under Prof. Paul Crutzen
- 1995-2000 Leader of the "Junior Group for Aerosol Chemistry and Microphysics" at MPI for Chemistry, Mainz, Germany
- Since 1996 Coordinator and Mission Scientist of various field campaigns involving the Russian high altitude research aircraft Geophysica
- 1997-2013 Member, 2007-2012 Co-Chair of the "Scientific Steering Group" of SPARC, core project of the World Climate Research Programme (WCRP)
- Since 1998 Co-author/reviewer of UNEP/WMO "Scientific Assessment of Ozone Depletion"
- Since 1999 Professor for atmospheric chemistry, ETH Zurich, Switzerland
- Since 2013 Head of Department, Department of Environmental Systems Science, ETH Zurich
- Publications in the Web-of-Science: 247, 7945 times cited, h-index 50

Distinctions and Honours:

- 1981/82 Fulbright fellow, University of Maryland, Maryland, U.S.A.
- Oct. 1987 Post-Graduate Fellow of the Academy of Sciences of the USSR, Lebedev
- Physics Institute, Moscow, USSR
- Since 1999 Member of Academia Europaea
- 2002 Charney Lecturer, AGU Spring Meeting, Baltimore, MD, U.S.A.
- 2010 Distinguished Lecturer, "The Golden Owl", ETH Zurich, Switzerland

Selected Related Publications:

Engel I., Luo B.P., Pitts M.C., Poole L.R., Hoyle C.R., Grooß J.-U., Dörnbrack A., Peter T., Heterogeneous formation of polar stratospheric clouds - Part 2: Nucleation of ice on synoptic scales, *Atmos. Chem. Phys., 13*, 10769-10785, 2013.

Hoyle C.R., Engel I., Luo B.P., Pitts M.C., Poole L.R., Grooß J.-U., Peter T., Heterogeneous formation of polar stratospheric clouds - Part 1: Nucleation of nitric acid trihydrate (NAT), *Atmos. Chem. Phys., 13,* 9577-9595, 2013.

Waibel A.E., Peter T., Carslaw K.S., Oelhaf H., Wetzel G., Crutzen P.J., Poschl U., Tsias A., Reimer E., Fischer H., Arctic ozone loss due to denitrification, *Science, 283*, 2064-2069, 1999.

Peter T., Microphysics and heterogeneous chemistry of polar stratospheric clouds, *Annu. Rev. Phys. Chem., 48*, 785-822, 1997.

Peter T., Bruhl C., Crutzen P.J., Increase in the PSC-formation probability caused by high-flying aircraft, *Geophys. Res. Lett., 18*, 1465-1468, 1991.

Dr. Simon P. Alexander

Experience related to the project

- Research into the role of orographic gravity waves on PSC composition and occurrence
- World Meteorological Organisation *Scientific Assessment of Ozone Depletion: 2014,* Chapter 3 "Polar Ozone" co-author
- Field experience: ground-based lidar observations of PSCs made at Davis, Antarctica during winter 2009

Education and career summary

2010 – present Senior Research Scientist *Australian Antarctic Division, Australia*
2008 – 2010 Research Scientist *Australian Antarctic Division, Australia*
2004 – 2008 JSPS Postdoctoral Research Fellowship *Kyoto University, Japan*
2004 PhD, Atmospheric Physics *University of Adelaide, Australia*
2000 BSc (First Class Honours), Physics *University of Canterbury, New Zealand*

Career Highlights

- World Meteorological Organisation *Scientific Assessment of Ozone Depletion: 2014,* Chapter 3 "Polar Ozone" co-author
- 26 publications in international peer-reviewed journals (lead author on 15). h-index=10, citations=299 (source: Google Scholar). Author of one book chapter.
- Reviewer for numerous journals including: *Geophysical Research Letters, Journal of Geophysical Research (Atmospheres), Quarterly Journal of the Royal Meteorological Society*
- Honorary Fellow at the Department of Physics, University of Tasmania (2008 – present) and Antarctic Climate and Ecosystems CRC, University of Tasmania (2013 – present)
- Member of the 2009 Davis, Antarctica (69°S, 78°E) wintering party

Selected publications related to the project

Alexander, S. P., A. R. Klekociuk, M. C. Pitts, A. J. McDonald, and A. Arevalo -Torres (2011), 'The effect of orographic gravity waves on Antarctic polar stratospheric cloud occurrence and composition', *Journal of Geophysical Research*, **116**, D06109, doi:10.1029/2010JD015184

Klekociuk, A.R., Tully, M.B., Alexander, S.P., Dargaville, R.J., Deschamps, L.L., Fraser, P.J., Gies, H.P., Henderson, S.I., Javorniczky, J., Krummel, P.B., Petelina, S.V., Shanklin, J.D., Siddaway, J.M. and Stone, K.A. (2011), 'The Antarctic Ozone Hole during 2010', *Australian Meteorological and Oceanographic Journal*, **61**, 253-267

Alexander, S. P., A. R. Klekociuk, A. J. McDonald, M. C. Pitts (2013), Quantifying the role of orographic gravity waves on polar stratospheric cloud occurrence in the Antarctic and the Arctic, *Journal of Geophysical Research*, **118**, 11,493 – 11,507, doi:10.1002/2013JD020122

Dr. Francesco Cairo

Education:

Ph. D. in Optics with a mark of 70/70 with praise, Università degli Studi di Firenze, 2000

Master in Advanced Calculus, with a mark of 110/110 with praise, Università degli Studi di Roma "La Sapienza", 2013

University degree in Physics with a mark of 110/110, Università degli Studi di Roma "La Sapienza", 1992

Professional Experience:

Senior Scientist, Italian Institute of Atmospheric Sciences and Climate, Department of Earth and Environment, Italian National Research Council, 2002-present

Scientist, Italian Institute of Atmospheric Physics, Department of Earth and Environment, Italian National Research Council, 1993-2001

Summary of Relevant Research Experience:

Coordinator of the CNR project BETACLOR for the implementation of optical probes for measuring particulate matter.

Workpackage leader for many European projects: HIBISCUS (Impact of tropical convection on the upper troposphere and lower stratosphere at global scale); TROCCINOX (Tropical Convection, Cirrus, and Nitrogen Oxides Experiment); SCOUT-O3 Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere); RECONCILE (Reconciliation of essential process parameters for an enhanced predictability of arctic stratospheric ozone loss and its climate interaction); EUFAR (European Fleet for Airborne Research); STRATOCLIM (Stratospheric and upper tropospheric processes for better climate predictions).

Coordinator of the PNRA project "Improvement of LIDAR Observatories for the NDSC in Antarctic", managing the activity of two LIDAR stations in the Antarctic stations of Mcmurdo and Dumont d' Urville.

Honors/Awards: Accademia dei Lincei "Felice Ippolito" prize for research on polar stratospheric microphysics, 2006.

Selected Relevant Publications:

Dr. Cairo is the author or co-author of over 60 peer-reviewed publications. Recent publications directly relevant to this proposal:

Molleker S.; Borrmann S.; Schlager H.; Luo B.; Frey W.; Klingebiel M.; Weigel R.; Ebert M.; Mitev V.; Matthey R.; Woiwode W.; Oelhaf H.; Dornbrack A.; Stratmann G.; Grooss J.-U.; Gunther G.; Vogel B.; Muller R.; Kramer M.; Meyer J.; Cairo F.: Microphysical properties of synoptic-scale polar stratospheric clouds: In situ measurements of unexpectedly large HNO3-containing particles in the arctic vortex in *Atmos. Chem. Phys.,* 14, 10785-10801, 2014.

Di Liberto, Luca; Cairo, Francesco; Fierli, Federico; Di Donfrancesco, Guido; Viterbini, Maurizio; Deshler, Terry; Snels, Marcel (2014). Observation of polar stratospheric clouds over McMurdo (77.85 degrees S, 166.67 degrees E) (2006-2010), *J. Geophys. Res.*, 110, 5528-5541, 2014.

von Hobe M., et al.: Reconciliation of essential process parameters for an enhanced predictability of Arctic stratospheric ozone loss and its climate interactions (RECONCILE): activities and results, *Atmos. Chem. Phys.*, 13, 9233-9248, 2013.

Dr. Terry Deshler

Education:

Ph. D., Physics, University of Wyoming, 1982
M. S., Atmospheric Sciences, University of Wyoming, 1975
B. A., Mathematics, University of Wyoming, 1969

Professional Experience:

Professor Emeritus, Atmospheric Science, University of Wyoming, 2014-present
Professor, Atmospheric Science, University of Wyoming, 1999-2014
Associate Professor, Dept. of Atmospheric Science, University of Wyoming, 1994-1999
Assistant Professor, Dept. of Atmospheric Science, University of Wyoming, 1991-1994
Research Scientist, Department of Physics and Astronomy, University of Wyoming, 1988-1991
Meteorologist, Bureau of Reclamation, US Department of Interior, Auburn, CA, 1985-1988
Software Engineer, In-Situ Inc., Laramie, WY, 1982-1985

Polar stratospheric cloud publications since 2003 (PSC publications began in 1989):

Ward, S. M., T. Deshler, and A. Hertzog (2014), Quasi-Lagrangian measurements of nitric acid trihydrate formation over Antarctica, *J. Geophys. Res. Atmos., 119,* doi:10.1002/2013JD020326.

Wang, Z., G. Stephens, T. Deshler, C. Trepte, T. Parish, D. Vane, D. Winker, D. Liu, and L. Adhikari (2008), Association of Antarctic polar stratospheric cloud formation on tropospheric cloud systems, *Geophys. Res. Lett.*, 35, L13806, doi:10.1029/2008GL034209.

Weisser, C., K. Mauersberger, J. Schreiner, N. Larsen, F. Cairo, A. Adriani, J. Ovarlez, and T. Deshler (2006) Composition analysis of liquid particles in the Arctic stratosphere under synoptic conditions, *Atmos. Chem. Physics, 6*, 689-696.

Scarchilli, C., A. Adriani, F. Cairo, G. Di Donfrancesco, C. Buontempor, M. Snels, M. L. Moriconei. T. Deshler, N. Larsen, B. Luo, K. Mauersberger, J. Ovarlez, J. Rosen, and J. Schreiner (2005), Determination of PSC particle refractive indices using in situ optical measurements and T-Matrix calculation. *Appl. Optics*, *16*, 3302-3311.

Eidhammer, T., and T. Deshler (2005), Evaporation of polar stratospheric particles in situ in a heated inlet, *Atmos. Chem. Physics*., *5*, 97-106

Larsen, N., B. M. Knudsen, S. H. Svendsen, T. Deshler, J. M. Rosen, R. Kivi, C. Weisser, J. Schreiner, K. Mauersberger, F. Cairo, J. Ovarlez, H. Oelhaf, and A. Schmidt (2004), Formation of solid particles in synoptic-scale Arctic PSCs in early winter 2002/2003. *Atmos. Chem. Physics*., 4, 2001-2013.

Deshler, T., N. Larsen, C. Weisser, J. Schreiner, K. Mauersberger, F. Cairo, A. Adriani, G. Di Donfrancesco, J. Ovarlez H. Ovarlez, U. Blum, K.H. Fricke, and A. Dörnbrack (2003), Large nitric acid particles at the top of an Arctic stratospheric cloud, *J. Geophys. Res*., 108(D16), 4517, doi:10.1029/2003JD003479.

Vogel, B., R. Müller, T. Deshler, J.-U. Grooβ, J. Karhu, D. S. McKenna, M. Müller, D. Toohey, G. C. Toon, and F. Stroh (2003), Vertical profiles of activated ClO and ozone loss in the Arctic vortex in January and March 2000: In situ observations and model simulations, *J. Geophys. Res., 108(D22)*, 8334, doi:10.1029/2002JD002564.

Voigt, C., N. Larsen, T. Deshler, C. Kröger, J. Schreiner; K. Mauersberger, B. Luo, A. Adriani, F. Cairo, G. Di Donfrancesco, J. Ovarlez, H. Ovarlez, A. Dörnbrack, B. Knudsen, J. Rosen (2003), In situ mountain-wave polar stratospheric cloud measurements: Implications for nitric acid trihydrate formation *J. Geophys. Res., 108* (D5) 10.1029/2001JD001185.

Dr. Jens-Uwe Grooß

Education:

Ph. D., Max-Planck Institute for Chemistry, Mainz, Germany 1996
Diploma in Physics, University of Mainz, Germany 1992

Professional Experience:

Research Scientist at ICG-1, later IEK-7, Forschungszentrum Jülich 1997-present
PostDoc, Max-Planck-Institute for Chemistry, Mainz 1996-1997

Summary of Relevant Research Experience:

Dr. Jens-Uwe Grooß has a long standing history in modelling stratospheric chemistry including the effects of Polar Stratospheric Clouds on denitrification and ozone. In his PhD work (1992-1995) he incorporated temperature statistics into the Mainz 2-D model to overcome the extreme non-linearity of PSC formation and resulting chlorine activation in a zonally averaged model formulation. Since 1997, he developed the chemistry and microphysics code of the Chemical Lagrangian Model of the Stratopshere (CLaMS) at the Jülich Research Center. One focus of his work was the vertical re-distribution of NOy through sedimenting NAT particles. For that, he extended the Lagrangian concept of CLaMS to simulating individual particle trajectories.

Selected Relevant Publications:

Grooß, J.-U., Modelling of stratospheric chemistry based on HALOE/UARS satellite data, PhD thesis, University of Mainz, 1996.

McKenna, D. S., **J.-U. Grooß**, G. Günther, P. Konopka, R. Müller, G. Carver, and Y. Sasano, A new Chemical Lagrangian Model of the Stratosphere (CLaMS): Part II Formulation of chemistry-scheme and initialisation, *J. Geophys. Res.*, *107* (D15), 4256, 2002.

Grooß, J.-U., G. Günther, R. Müller, P. Konopka, S. Bausch, H. Schlager, C. Voigt, C. M. Volk, and G. C. Toon, Simulation of denitrification and ozone loss for the Arctic winter 2002/2003, *Atmos. Chem. Phys.* , *5*, 1437-1448, 2005.

Peter, T. and **J.-U Grooß** Polar Stratospheric Clouds and Sulfate Aerosol Particles: Microphysics, Denitrification and Heterogeneous chemistry, Stratospheric Ozone Depletion and Climate Change, ed. Rolf Müller, RSC Publishing, p. 108-144, 2011.

Wegner, T., **J.-U. Grooß**, M. von Hobe, F. Stroh, O. Sumińska-Ebersoldt, C. M. Volk, E. Hösen, V. Mitev, G. Shur, and R. Müller, Chlorine activation on stratospheric aerosols: Uncertainties in parameterizations and surface area, *Atmos. Chem. Phys.*, *12*, 11095-11106, 2012.

Hoyle, C. R., I. Engel, B. P. Luo, M. C. Pitts, L. R. Poole, **J.-U. Grooß**, and T. Peter, Heterogeneous formation of polar stratospheric clouds - Part 1: Nucleation of nitric acid trihydrate (NAT), *Atmos. Chem. Phys.*, *13*, 9577-9595, 2013.

Woiwode, W., **J.-U. Grooß**, H. Oelhaf, S. Molleker, S. Borrmann, A. Ebersoldt, W. Frey, T. Gulde, S. Khaykin, G. Maucher, C. Piesch, and J. Orphal, Denitrification by large NAT particles: the impact of reduced settling velocities and hints on particle characteristics, *Atmos. Chem. Phys.*, *14*, 11525-11544, 2014.

Molleker, S., et al., Microphysical properties of synoptic-scale polar stratospheric clouds: in situ measurements of unexpectedly large HNO_3 containing particles in the Arctic vortex, *Atmos. Chem. Phys.*, *14*, 10785-10801, 2014.

Grooß, J.-U., I. Engel, S. Borrmann, W. Frey, G. Günther, C. R. Hoyle, R. Kivi, B. P. Luo, S. Molleker, T. Peter, M. C. Pitts, H. Schlager, G. Stiller, H. Vömel, K. A. Walker, and R. Müller, Nitric acid trihydrate nucleation and denitrification in the Arctic stratosphere, *Atmos. Chem. Phys.*, *14*, 1055-1073, 2014.

Dr. Michael Höpfner

Education:

Habilitation, Meteorology, University of Karlsruhe, 2008
Ph. D., Meteorology, University of Karlsruhe, 1994
Diploma, Physics, University of Karlsruhe, 1991

Professional Experience:

Senior Research Scientist and Lecturer, Karlsruhe Institute of Technology, 2008-present
Research Scientist, Forschungszentrum Karlsruhe 1996-2008
Stay for Research, Istituto Di Ricerca Sulle Onde Elettromagnetiche, Florence 1995-1996

Summary of Relevant Research Experience:

Dr. Höpfner's research is directed towards the retrieval and analysis of atmospheric parameters from passive remote sounding observations in the infrared spectral region. He was part of the team developing the official ESA processor for analysis of spectra from the space-borne limb-emission sounder MIPAS on board the Envisat satellite. He also developed major parts of the processing scheme for scientific analysis of MIPAS data at the Institute for Meteorology and Climate research (IMK) in Karlsruhe. Dr. Höpfner has made major contributions regarding the retrieval of polar stratospheric cloud (PSC) parameters from infrared limb-observations and to PSC research in general. Currently he is co-leader of the research team at IMK deploying the infrared limb-imaging instrument GLORIA at high-flying aircraft - involving a polar measurement campaign during the upcoming Arctic winter 2015/16.

Selected Relevant Publications:

Dr. Michael Höpfner is author and co-author of more than 110 publications in peer-reviewed journals. Subjects include: level 1 data analysis of FTIR spectrometers, radiative transfer modelling, and remote sensing of atmospheric trace gases and of polar stratospheric clouds.
Recent publications directly relevant to this proposal:

M. Höpfner et al., Mountain polar stratospheric cloud measurements by ground based FTIR solar absorption spectroscopy, *Geophys. Res. Lett.*, 28(11), 2189, 2001.

M. Höpfner et al., Evidence of scattering of tropospheric radiation by PSCs in mid-IR limb emission spectra: MIPAS-B observations and KOPRA simulations, *Geophys. Res. Lett.,* 29(8), 1278, 2002.

M. Höpfner et al., Spectroscopic evidence for NAT, STS, and ice in MIPAS infrared limb emission measurements of polar stratospheric clouds, *Atmos. Chem. Phys.*, 6, 1201-1219, 2006.

M. Höpfner et al., MIPAS detects Antarctic stratospheric belt of NAT PSCs caused by mountain waves, *Atmos. Chem. Phys.*, 6, 1221-1230, 2006.

S.D. Eckermann et al., Antarctic NAT PSC belt of June 2003: Observational validation of the mountain wave seeding, *Geophys. Res. Lett*., 36, L02807, 2009.

M. Höpfner et al., Comparison between CALIPSO and MIPAS observations of polar stratospheric clouds, *J. Geophys. Res*., 114, D00H0536, 2009.

Dr. Alyn Lambert

Education:

Ph. D., Physics, University of Leeds, UK, 1986

B. Sc., Physics with Astrophysics (with First Class Honours), University of Leeds, UK, 1982

Professional Experience:

2005–Present: Research Scientist, Microwave Atmospheric Science Group, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA. Microwave Limb Sounder (MLS) scientist responsible for the stratospheric water vapor, nitrous oxide and cloud ice data products. PI: Polar Processing Studies of the Arctic and Antarctic: New constraints from A-Train Observations and the WACCM-SD/CARMA Model (2014–). Co-I: A Compact Adaptable Microwave Limb Sounder for Atmospheric Composition (2014–). PI: CALIPSO and MLS Observations of Atmospheric Composition and Polar Stratospheric Cloud Formation and Evolution (2010–2012). PI: Near real time data products from Aura MLS (2008–2009). Co-I: Retrieval and analysis of new cloud products from Aura MLS (2008–2010).

1998 – 2005: Project Scientist I/II, High Resolution Dynamics Limb Sounder (HIRDLS) Co-I and Lead Retrieval Scientist, Global Atmospheric Change Group, Atmospheric Chemistry Division, National Center for Atmospheric Research, Boulder, USA

1991–1998: Senior Research Associate, UARS/ISAMS and Galileo/NIMS projects, Atmospheric, Oceanic and Planetary Physics, University of Oxford, UK.

1988–1990: Research Collaborator, GRANAT/SIGMA project, Service d'Astrophysique, Commissariat `a l'Energie Atomique, Centre d'Etudes Nucl´eaires de Saclay, CEN-SACLAY, France.

1986–1988: Research Fellow, Haverah Park Cosmic Ray Physics Group, Department of Physics, University of Leeds, Leeds, UK.

Summary of Relevant Research Experience:

Over 30 years experience in satellite data research involving astrophysical and atmospheric instruments. Extensive experience in retrieval algorithms and radiative transfer modeling for infrared and microwave instruments. Retrieving atmospheric temperature and constituent concentrations using optimal estimation techniques, performing sensitivity studies, validating and interpreting atmospheric data. Investigating the properties of sulfuric acid aerosols and polar stratospheric clouds using multi-wavelength retrievals of temperature, gas species, aerosol extinction and backscatter.

Honors/Awards:

NASA Group Achievement Awards for EOS Aura (2005), HIRDLS (2006), MLS (2006, 2014), TC4 (2008), ARCTAS (2009); NASA Space Act Awards for MLS (2007, 2010).

Selected Relevant Publications:

Author or co-author of 77 refereed journal papers.

Millan, L., Read, W., Kasai, Y., Lambert, A., Livesey, N., Mendrok, J., Sagawa, H., Sano, T., Shiotani, M. and Wu, D. L., SMILES ice cloud products, *J. Geophys. Res., 118*, 6468–6477, 2013.

Pitts, M. C., Poole, L. R., Lambert, A., and Thomason, L. W., An assessment of CALIOP polar stratospheric cloud composition classification, *Atmos. Chem. Phys., 13*, 2975–2988, 2013.

Lambert, A. et al, A-train CALIOP and MLS observations of early winter Antarctic polar stratospheric clouds and nitric acid in 2008, *Atmos. Chem. Phys., 6,* 2899–2931, 2012.

Santee, M.L., A. Lambert et al, Validation of the Aura Microwave Limb Sounder ClO Measurements, *J. Geophys. Res. 113*, D15S22, doi:10.1029/2007JD008762, 2008.

Lambert, A. et al, Validation of the Aura Microwave Limb Sounder middle atmosphere water vapor and nitrous oxide measurements, *J. Geophys. Res. 112*, D24S36, doi:10.1029/2007JD008724, 2007.

Santee, M.L., A. Lambert, et al, Validation of Aura Microwave Limb Sounder HNO3 Measurements, *J. Geophys. Res. 112*, D24S40, doi:10.1029/2007JD008721, 2007.

Dr. Sergej Molleker (*Young Scientist*)

Education:

Ph.D., Max Planck Institute for Chemistry, University of Mainz, October 2013
Thesis: "Characterization of optical particle probes and microphysical properties of Polar Stratospheric Clouds in the Arctic as derived from in-situ measurements"

Diploma in Physics, Technical University of Darmstadt, Germany, November 2007
Thesis: "Frequency-doubling of the radiation from a fiber amplifier in an external build-up cavity without temperature stabilization"

Professional Experience:

Scientific employee at Max Planck Institute for Chemistry, Particle Chemistry Department, Mainz, Germany, 2014-present

Ph. D. student at the Max Planck Institute for Chemistry, 2008-2013

ERASMUS exchange student at University of Bath, England, 2004-2005

Summary of Relevant Research Activities:

Dr. Sergej Molleker's research has been focused on airborne in situ measurements of cloud particles. His Ph.D concentrated on polar stratospheric cloud (PSCs) research through field work with a strong focus on airborne in situ measurements of PSC particles size distributions. Together with his colleagues at the Max Planck Institute for Chemistry, he analyzed in situ measurements of unexpectedly large NAT PSC particles, which called into question the conventional understanding of NAT particle nucleation, growth, and sedimentation.

Selected Publications

Klingebiel, M., de Lozar, A., **Molleker, S.**, Weigel, R., Roth, A., Schmidt, L., Meyer, J., Ehrlich, A., Neuber, R., Wendisch, M., and Borrmann, S.: Arctic low-level boundary layer clouds: in situ measurements and simulations of mono- and bimodal supercooled droplet size distributions at the top layer of liquid phase clouds, Atmos. Chem. Phys., 15, 617-631, doi:10.5194/acp-15-617-2015, 2015.

Molleker, S., Borrmann, S., Schlager, H., Luo, B., Frey,W., Klingebiel, M., Weigel, R., Ebert, M., Mitev, V., Matthey, R., Woiwode, W., Oelhaf, H., Dörnbrack, A., Stratmann, G., Grooß, J.-U., Günther, G., Vogel, B., Müller, R., Krämer, M., Meyer, J., and Cairo, F.: Microphysical properties of synoptic-scale polarstratospheric clouds: in situ measurements of unexpectedly large HNO_3-containing particles in the Arctic vortex, Atmos. Chem.Phys., 14, 10785–10801, doi:10.5194/acp-14-10785-2014, 2014.

Woiwode, W., Grooß, J.-U., Oelhaf, H., **Molleker, S.**, Borrmann, S., Ebersoldt, A., Frey, W., Gulde, T., Khaykin, S., Maucher, G., Piesch, C., and Orphal, J.: Denitrification by large NAT particles:the impact of reduced settling velocities and hints on particle characteristics, Atmos. Chem. Phys. Discuss., 14, 5893–5927,doi:10.5194/acpd-14-5893-2014, 2014.

Dr. Ross J. Salawitch

Education:

Cornell University, 1981, B.S., Applied and Engineering Physics.

Harvard University, 1987, Ph.D. in Applied Physics.

Thesis: *Antarctic Ozone: Theory and Observation*, Adviser: M. B. McElroy.

Professional Experience:

Professor (2007 to present), University of Maryland, Dept. of Atmospheric and Oceanic Science, Dept. of Chemistry and Biochemistry, and Earth System Science Interdisciplinary Center, College Park, Maryland.

Senior Research Scientist (2006–2007), Principal Scientist (2003–2006) and Research Scientist (1994 –2003), Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

Visiting Research Associate (1997 to 2003) and Visiting Faculty Associate (2003 to present), California Institute of Technology, Pasadena, CA.

Research Associate and Postdoctoral Fellow, Harvard University, 1988 to 1994.

Research Interests:

Quantification of the effects of human activity on the composition of Earth's atmosphere by comparison of observations to computer model simulations. Participant in numerous international ozone expeditions and author of more than 100 publications in the peer reviewed literature describing Earth's ozone layer.

Selected Publications: **(Full list at http://www.researcherid.com/rid/B-4605-2009)**

Bloomer, B.J. *et al.*, Observed relationships of ozone air pollution with temperature and emissions, *Geophys. Res. Lett.*, *36*, L09803, doi:10.1029/2009GL037308, 2009.

Canty, T., *et al.*, Stratospheric and mesospheric HO_x: Results from Aura MLS and FIRS-2, *Geophys. Res. Lett, 33,* L12802, doi:10.1029/2006GL025964, 2006.

McElroy, M.B., R.J. Salawitch, S.C. Wofsy, and J.A. Logan, Antarctic ozone: reductions due to synergistic interactions of chlorine and bromine, *Nature, 321*, 759-762, 1986.

Oman *et al*., L. D., Multi-model assessment of the factors driving stratospheric ozone evolution over the 21st century, *J. Geophys. Res.*, in press, 2010.

Osterman, G.B., *et al.*, Partitioning of NO_y species in the summer Arctic stratosphere, *Geophys. Res. Lett.*, *26*, 1157-1160, 1999.

Rex, M., *et al.,* Arctic ozone loss and climate change, *Geophys. Res. Lett.*, *31,* L04116, 2003GL018844, 2004.

Salawitch, R.J., Atmospheric chemistry: biogenic bromine, *Nature, 439*, 275-277, 2006.

Salawitch, R.J., G.P.Gobbi, S.C. Wofsy, and M.B. McElroy, Denitrification in the Antarctic stratosphere, *Nature, 339*, 525-527, 1989.

Salawitch, R.J. *et al*., Chemical loss of ozone in the Arctic polar vortex in the winter of 1991-92, *Science, 261*, 1146-1149, 1993.

Salawitch, R.J *et al*., Sensitivity of ozone to bromine in the lower stratosphere, *Geophys.Res. Lett.*, 32, L05811, 2004GL021504, 2005.

Salawitch, R. J. *et al.*, A new interpretation of total column BrO during Arctic spring, *Geophys. Res. Lett., 37*, L21805, doi:10.1029/2010GL043798, 2010.

Sen, B., *et al.*, Measurements of reactive nitrogen in the stratosphere, *J. Geophys. Res., 103*, 3571-3585, 1998.

Wennberg, P.O. *et al*., Hydrogen radicals, nitrogen radicals, and the production of O_3 in the upper troposphere, *Science, 279*, 49-53, 1998.

Yang, E.-S. *et al.*, Attribution of recovery in lower-stratospheric ozone, *J. Geophys. Res.*, *111*, D17309, doi:10.1029/2005JD006371, 2006.

Dr. Reinhold Spang

Education:

Ph.D., Physics, University of Wuppertal, Germany, 1997
Diploma in Geophysics, University of Cologne, Germany, 1990

Professional Experience:

Senior Scientist, Institute for Energy and Climate Research, Stratosphere (IEK-7), Forschungszentrum Jülich, Jülich, Germany, 2003-present
University of Leicester, Earth Observation Science Group, Post-doctoral RA, 2001-2003
Deputy coordinator of the EU Framework 6 Project MAPSCORE (polar processes in respect to ozone and polar stratospheric clouds, coordinated by J.J. Remedios)
University of Wuppertal, Department of Physics, Post-doc Research Associate, 1997-2001
University of Wuppertal, Dep. of Physics – Atmosphere Physics, Research Assistant, 1991-1997

Summary of Relevant Research Experience:

Dr. Spang has more than 20 years experience in the analysis of IR remote sensing data, software development of level 0 to level 2 processing, and the interpretation of cloud measurements in the upper troposphere and stratosphere region. He has coordinated and participated various ESA projects focusing on recent and future atmospheric IR limb sounders (e.g. MIPAS, CRISTA-NF, GLORIA-AB). Since more than 15 years he is investigating the analysis of cloud contaminated IR spectra in respect of cloud detection and classification, cloud clearing for trace gas retrievals, cloud chemical processes like PSC formation and denitrification of the polar vortices, as well as sub-visible cirrus related cloud processes.

Selected Relevant Publications:

Griessbach, S., Hoffmann, L., Höpfner, M., Riese, M., and Spang, R.: Scattering in infrared radiative transfer: A comparison between the spectrally averaging model JURASSIC and the line-by-line model KOPRA, *J. Quant. Spectrosc. Radiat. Transfer*, Vol. 127, pp. 102-118, 2013.

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