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SPARC

Stratosphere-troposphere
Processes And their Role in Climate

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The ice shelf near the Mertz Glacier, Antarctica. The link between polar regions and extra-tropical climate is still a topic of intense research, some of which is coordinated through the WCRP Polar Climate Prediction Initiative (see p21). Photo credit: Noé Sardet, EPFL/Parafilms (taken during the recent Antarctic Circumpolar Expedition, organised by the Swiss Polar Institute).

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World Climate Research Programme
WMO
IOC
International Council for Science

38th Session of the WCRP Joint Steering Committee

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The 38th session of the WCRP Joint Steering Committee (JSC) was hosted by one of the three WCRP sponsors, namely the intergovernmental Oceanographic Commission (IOC). The meeting was held at the IOC headquarters in Paris from 3-6 April 2017. Attending on behalf of SPARC were the co-chairs, **Judith Perlwitz** and **Neil Harris**, and the project office director, **Fiona Tummon**.

WCRP Strategy Discussion

The first day of the meeting was dedicated to discussing the new WCRP strategy, which will be presented as part of the review that WCRP is currently undergoing for its three sponsors: The World Meteorological Organisation (WMO), the IOC, and the International Council for Science (ICSU). Discussions were led by **Guy Brasseur**, JSC chair, who also opened the meeting by welcoming all participants. Several issues were highlighted, such as the need for WCRP to articulate the case for climate research, since no adaptation or mitigation is possible without fundamental climate science providing our best current knowledge. WCRP also needs to provide links between the various temporal and spatial scales, particularly the global and regional, the latter of which is where climate information is most urgently needed. Further focus should fall on how WCRP does its outreach, particularly beyond the traditional scientific community. It is essential that WCRP enhances connections with the stakeholders that could use the information that WCRP research provides, for example, disaster risk managers or engineers dealing with sea level rise. These connections need to allow for two-way interactions to ensure that WCRP science remains societally relevant. This strategy document is currently being drafted, with input from the core projects expected.

WCRP Sponsors and sister organisations

Vladimir Ryabinin, assistant director general of the IOC, opened by mentioning that the IOC defends the values of science and honesty, particularly in the sense that good science is essential to supporting good decision making. The role of the IOC is to bring knowledge about the world's oceans to bear on various issues, as well as to build global capacity focused on the oceans. The IOC runs various important programmes, such as the Global Ocean Observing System (GOOS) and regional tsunami warning systems, and is responsible for maritime protected areas. Together with WCRP, the IOC helped organise a recent conference on sea level rise held in New York, USA, where a new report on ocean sciences was unveiled. WCRP is a major source of knowledge, experience, and talent for the IOC and the IOC is fully supportive of WCRP, doing its best to provide what funding and leadership it can as WCRP sponsor.

The WMO (represented by **Elena Manaenkova**, deputy secretary general) is aiming to better link its three research programmes, namely WCRP, the World Weather Research Programme (WWRP), and Global Atmosphere Watch (GAW). This is in an effort to provide seamless weather and climate products through a chain of services that should aim to reduce disaster risk, improve resilience, and allow for sustainable development in the face of climate change. The WMO is looking forward to working together with the IOC and ICSU to ensure an effective review of the WCRP. This was echoed by **Heide Hackmann**, executive director of WCRP's third sponsor ICSU, who also mentioned that the review provided an excellent opportunity for WCRP to develop a compelling strategic plan as well as to better define its relationship with its three co-sponsors. She also noted that ICSU is currently considering merging with the International Social Science Programme (ISSP), a discussion that was begun in 2014 when ICSU itself underwent a review.

The Paris Agreement was based on science, in large part underpinned by the work of WCRP (**Florian Vladu**, United Nations Framework Convention on Climate Change (UNFCCC)). By supporting the

IPCC assessments, WCRP has played a key role in the cycle that goes all the way from observations through to policy making; all of which is essential to meet the sustainable development goals. WCRP participated in a recent meeting of UNFCCC's Subsidiary Body for Scientific and Technological Advice, which was seen as very useful, particularly to help address the major funding issues facing the research community.

Valérie Masson-Delmotte, co-chair of IPCC Working Group One, outlined the progress made so far towards defining the scope of the sixth assessment report as well as the three special reports which will focus on the 1.5°C warming scenario, the oceans and cryosphere, and the land surface, respectively. A recurrent theme across the latter two is that of risk management, which will be specifically addressed in both reports. The 1.5°C report is the first due to be completed, with a deadline for contributing papers to be accepted by 15 May 2018. The timeline for the other two reports as well as the sixth assessment are still under discussion.

Future Earth, which focuses very broadly on sustainability and stakeholder engagement, is continuing to ensure good collaboration with WCRP (**Thorsten Kiefer**). So far, the strongest links have been at the project level, for example, between SPARC and IGAC (International Global Atmospheric Chemistry), but there is also collaboration with the WCRP Grand Challenges and the Future Earth Knowledge Action Networks, as well as further opportunities to work together to contribute to the IPCC special reports. Finally, there is engagement across the two communities at the early career level through the 'Network of Networks', a grouping of the various early career researcher networks from both programmes. Thorsten also highlighted the Future Earth Open Network (**http://network.futureearth.org/home**), which is an online communication platform that has a wide range of capabilities that can be freely used by all registered users.

WCRP regional activities

A scoping workshop was held in early 2017 in Hamburg, Germany, with the aim of better defining where WCRP can play a role in regional climate-related activities. The participants drafted a set of recommendations that focused around three "legs" on which the framework for WCRP regional activities would rest. These three "legs" were: fundamental climate science, application-inspired climate science, and transdisciplinary engagement. It was noted that the WCRP regional activities should go beyond what CORDEX does and that there needs to be real engagement with the various regions since there is already a wide range of ongoing activities at this level. It was also mentioned that it was vital that links be made with the VIACS (Vulnerability, Impacts, Adaptation, and Climate Services) activity that is part of CMIP6 (see below).

CORDEX (**Bill Gutowski**) has developed and refined their scientific vision over the past 2-3 years. Part of this revisioning has been focused around scientific challenges which aim to provide concrete examples of where regional downscaling can provided added value. A recent example, showed using high resolution regional models (12km resolution), that future high-altitude precipitation over the European Alps is likely to increase due to enhanced convection, in contrast to what lower resolution simulations have previously shown (Giorgi *et al.*, 2016).

One of CORDEX's biggest activities in the past year was the ICRC Conference in Stockholm, Sweden, which was organised various scientific challenges so that researchers focused on different regions participated in session together. There was also a discussion led by early career researchers about how they could be more engaged in CORDEX science. CORDEX also participated in the climate services conference which was held in February 2017 in Cape Town, South Africa, and has organised a series of workshops focused on statistical downscaling in an effort to further advance these techniques.

CMIP6

Gerry Meehl, of the Coupled Model Intercomparison Project (CMIP) Panel, described the CMIP6 experimental design that includes base simulations which all modelling teams will run as well as the large range of sub-projects to which groups will contribute differently. Currently 32 modelling groups will participate in CMIP6, a large increase from the 11 involved in CMIP5. Two model performance metric tools have been developed, the ESMVal Tool and the PCMDI Metrics Package, which will initially be made available to modelling centres, then to other researchers. An online tool will also be created to subset the huge datasets that will be produced. The core CMIP6 simulations are to be run in late 2017 and 2018, however, before these are begun various forcing datasets, mostly those focused on future scenarios, need to be completed.

WCRP core projects

Judith Perlwitz and **Neil Harris** both made presentations during the SPARC parallel session. Neil presented some recent SPARC science highlights, including results from the reports on carbon tetrachloride and the SPARC data initiative, as well as from the very unusual disruption to the quasi-biennial oscillation which occurred in 2016. Judith focused on how SPARC contributes to climate dynamics activities across WCRP, both directly through SPARC activities as well as through organisation of cross-cutting workshops and training schools. During the subsequent discussions the links between SPARC and various other projects and programmes, for example, with GAW and IGAC, as well as between the SPARC SATIO-TCS activity, GEWEX, and the Grand Challenge on Clouds, Circulation, and Climate Sensitivity (see below).

The summary of the CliC session, which was held in parallel to the SPARC discussion, was presented by **Gerhard Krinner**, who is stepping down as CliC co-chair at the end of 2017 (to be replaced by Fiamma Straneo). CliC's structure is fairly similar to that of SPARC, with limited-lifetime activities, but also with several long-term groups and panels. Over the past few years they have significantly increased the number of modelling activities, and in general the cryospheric research community has grown considerably given the high-profile nature of science related to the rapid changes currently occurring in the Arctic. There is an increasingly crowded network of initiatives and project in this domain and thus coordination is key. CliC has several new activities of interest to the SPARC community, including the BEPSII project focused on biogeochemistry and linking observations with models, and a possible new focus on polar-lower latitude linkages. The latter of which, would have very clear links through the atmosphere and several of SPARC's activities.

CLIVAR has just completed its new science plan, which was widely discussed and largely finalised at their Open Science Conference in September 2016 (**Detlef Stammer**). This new plan has a number of long-term objectives that they aim to achieve through their various panels as well as through existing and new partnerships. CLIVAR has a number of regional activities, for example on Monsoons and upwelling regions, which have obvious links with other WCRP projects and other outside groups, such as the IOC, the Global Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS). As of April 2017, the CLIVAR office in China has a new executive director, Jose Santos, who was warmly welcomed to the WCRP community at the JSC meeting.

GEWEX has been making good progress across three of its four panels, with the fourth panel undergoing some major changes, particularly in terms of leadership (**Sonia Seneviratne**). There are obvious links between GEWEX and the Grand Challenges on extremes and water in the food baskets, as well as with other core projects through their Process Evaluation Studies (PROES). For example, SPARC has collaborated on the PROES focused on upper tropospheric convection and clouds (PROES-UTCC). A recent finding from this activity showed that as convective intensity increases the amount of thin high clouds increases, while thick high clouds decrease. Similar to SPARC, GEWEX is planning an Open Science Conference in 2018, although the dates and location remain to be confirmed.

Early Career Researchers

Sebastian Sonntag presented the report from the Young Earth System Scientists (YESS) community. He introduced the network and highlighted some of the achievements of the past year, which include the publication of a white paper, the establishment of a YESS Office with the support of the Argentinean MetService, and involvement in various international programmes. In the next year YESS plans to organise a second science workshop, continue involvement in WCRP activities, develop a working group on promoting interdisciplinary science, and to enhance its involvement in various international research programmes further.

WCRP Advisory Councils

Christian Jakob started the WCRP Modelling Advisory Committee (WMAC) report by highlighting the 2016 WWRP/WCRP modelling prize, which was awarded to Irina Sandu for her work on parameterisation of the planetary boundary layer.

Figure 1: *Participants at the 38th session of the WCRP Joint Scientific Committee held in Paris, France, from 3-6 April 2017.*

The 2017 call for this prize is currently open and all nominations can be made online at: **www.wcrp-climate.org/wmac-activities/ipmd2017**. WMAC is helping to organise the pan-WCRP model working group meeting which will take place from 9-13 October at the UK MetOffice. The council is also involved in the organisation of the 2nd WCRP model development summer school, which will focus on grey-zone parameterisations and is being hosted by CPTEC-INPE in Brazil in January 2018 (more information at: **http://eventos.cptec.inpe.br/wcrpsummerschool**). WMAC carried out a survey to get a clearer idea of the breadth of modelling activities across WCRP, finding that there are 67 individual modelling activities that focus on various aspects. There is thus a significant need for coordination, to ensure efficient use of resources throughout WCRP.

The WCRP data advisory panel (WDAC) will soon undergo a leadership change, with Jean-Noël Picot to take over from **Otis Brown** in the coming year. In 2016, WDAC initiated a Task Team for the Intercomparison of Reanalyses (TIRA), which has members from across the WCRP projects and working groups. The SPARC representative is Masatomo Fujiwara. Over the past months WDAC have also had several discussions with the GCOS to see how communications between the GCOS panels and WCRP projects, Grand Challenges, and working groups can be improved. This would be beneficial to both programmes, with WCRP being able to provide the scientific knowledge to understand the scientific drivers behind the observational requirements that are laid out by GCOS.

WCRP Grand Challenges

The Grand Challenge on Regional Sea-level Change and Coastal Impacts (**Detlef Stammer**) is a highly inter-disciplinary activity, since understanding sea-level change requires focusing on so many processes, for example, ground subsidence, glacial changes, and thermal expansion. The group has recently initiated the Coordinated Ocean Storm Surge Climate Project (COSSCLIP), which aims to improve the representation of storm surges in models, since these features are typically not included but cause much of the damage in coastal regions resulting from sea-level rise. The group was also very involved in athe aforementioned conference on sea level rise held in New York, USA, in June.

Gaby Hegerl presented the Grand Challenge on Understanding and Predicting Weather and Climate Extremes. They have had several very successful workshops over the past few years, and have produced quite a large number of papers as a result. The Grand Challenge focuses on four main extremes: heatwaves, droughts, heavy precipitation, and storms; and do so through four themes on documenting, understanding, simulating, and attributing these types of events. The group has made considerable effort to make links with the statistics community, as well as with paleoclimate researchers, the WWRP HiWeather project, and the Future Earth extremes community.

The Grand Challenge on Clouds, Circulation, and Climate Sensitivity is already going into its second five-year phase (**Sandrine Bony**). During this second period they will continue to develop the activity until 2021 or 2022, when they will conclude the Grand Challenge and establish how best to continue relevant activities, for example on storm tracks, through the core projects. The group is working hard on a review paper on climate sensitivity, led by Steve Sherwood and Mark Webb, which is due to be completed in 2018. They are also planning to make use of the DynVar diagnostic MIP data from CMIP6, particularly to look at the tropical rain belt, convective aggregation, and storm tracks. Finally, since a main source of uncertainty in models stems from low clouds, for which few observations are available, the Grand Challenge is heavily involved in the EREC4A experiment which is to make exactly such observations.

Jan Polcher presented the Grand Challenge on Water for Food Baskets, which is being led by GEWEX. The group have been working to refine the focus of this Grand Challenge and are planning several workshops in this context. They also would like to encourage the other WCRP core projects to become more involved as well as to reach out the other communities researching water resources. There is a clear link to SPARC through their focus on the impact of fertiliser use on air quality.

The mission of the Grand Challenge on Near-term Climate Predictions (**Masahide Kimoto**) is to bridge the gap between sub-seasonal to seasonal and IPCC-style century-scale projections. The group involved in this Grand Challenge has been very active, holding teleconferences every two months. SPARC was invited to give a presentation at one of these teleconferences and has been participating in the teleconferences. The WMO committee on basic systems endorsed the idea of a WMO lead centre for near-term climate prediction to ensure that these predictions become operational. Currently the UK MetOffice is the main candidate for this. The Grand Challenge has outlined the proposed content for the "global annual to decadal climate update" that will be produced. This includes a one-page executive summary, a description of current observations and various climate indices, as well as maps of several key variables for one year, years 1-5, and years 5-10. In addition, some description of the estimated forecast skill as well as an assessment of previous forecasts will be presented. The Grand Challenge is considering how to contribute to the IPCC Special Report on the 1.5°C Warming Scenario, likely through a summary of the climate outlook for the next decade.

The Grand Challenge on Carbon and Climate has, since the last JSC meeting in 2016, further developed its structure and leadership (**Pierre Friedlingstein**). The group organised their first workshop in Hamburg, where much of this was discussed. They have also defined two main activities for 2017, which focus on extending the framework for understanding and simulating carbon cycle feedbacks, as well as on understanding how feasible it might be to produce decadal predictions of the carbon cycle. This latter issue would be hugely relevant to the Intended Nationally Determined Contributions of the Paris Agreement, particularly in terms of the idea of a limited carbon budget. SPARC's emerging activity on short-lived climate forcers is to complement and contribute to the activities of this Grand Challenge.

The Grand Challenge on Melting Ice (**Gerhard Krinner**) falls directly under CliC and is mainly focused around modelling activities, many of which will contribute to CMIP6. There are also various collaborations between this Grand Challenge and permafrost networks, and in this respect, there are clear links with the Grand Challenge on Carbon and Climate.

New WCRP Communication Strategy

Narelle van der Wel provided an overview of the new WCRP communications strategy, which covers a wide range of planned activities. Considerable effort has been made to update the WCRP website and other communication material, including the community newsletter, templates for project reports, and other promotional material. The main objectives of the new strategy are to increase the visibility of WCRP, showcase WCRP science, inform and engage the WCRP community, build strategic partnerships – also with outside partners, and to encourage current and future leadership in climate science.

References

Giorgi, F., *et al.*, 2016: Enhanced summer convective rainfall at Alpine high elevations in response to climate warming. *Nature*, doi:10.1038/ngeo2761.

The SPARC Data Initiative – Results of a long journey

Susann Tegtmeier[1] and Michaela Hegglin[2]

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A new SPARC report providing an assessment of the availability and quality of stratospheric satellite trace gas observations was published in March 2017 (available at **www.sparc-climate.org/publications/sparc-reports**). This assessment was compiled by the SPARC Data Initiative team and includes the most up-to-date and comprehensive comparison of stratospheric constituent observations. The report provides knowledge and guidance to data users and chemistry-climate modellers, as well as feedback to instrument teams and space agencies about required improvements in existing datasets and the need for future observations.

The SPARC Data Initiative was started in 2009 by the co-leads **Michaela Hegglin** and **Susann Tegtmeier** and was endorsed as a SPARC activity the following year. The two co-leads brought together an international team of data analysts and instrument experts representing the most important limb sounders from the CSA, ESA, JAXA, NASA, SNSB, and other national space agencies (**Table 1**). The SPARC Data Initiative team has worked together over the last seven years to fulfill three major objectives:

1. Assessing the state of data availability from the multi-national suite of space-based instruments;
2. Compiling climatologies of chemical trace gases and making them available through the SPARC Data Centre;
3. Providing a detailed intercomparison of the trace gas climatologies.

During its first phase in 2010-2011, the SPARC Data Initiative successfully applied as an international team

***Table 1**: SPARC Data Initiative team including information on the role within the team (instrument represented or data analysis) and affiliation.*

John Anderson	HALOE	Hampton University, USA
Adam Bourassa	OSIRIS	University of Saskatchewan, Canada
Samuel Brohede	SMR	Chalmers University of Technology, Sweden
Doug Degenstein	OSIRIS	University of Saskatchewan, Canada
Lucien Froidevaux	Aura-MLS	Jet Propulsion Laboratory, California Institute of Technology, USA
Bernd Funke	MIPAS	Instituto de Astrofísica de Andalucía, CSIC, Spain
John Gille	HIRDLS	University of Colorado and NCAR, USA
Michaela Hegglin	Co-lead Data analysis	University of Reading, United Kingdom
Ashley Jones	ACE-FTS	University of Toronto, Canada
Yasuko Kasai	SMILES	NICT, Japan
Erkki Kyrölä	GOMOS	Finnish Meteorological Institute, Finland
Jerry Lumpe	POAM	Computational Physics, Inc., USA
Jessica Neu	TES Data analysis	Jet Propulsion Laboratory, California Institute of Technology, USA
Ellis Remsberg	LIMS	NASA Langley Research Center, USA
Alexei Rozanov	SCIAMACHY	University of Bremen, Germany
Susann Tegtmeier	Co-lead Data analysis	GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
Matthew Toohey	Data analysis Sampling	GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany
Joachim Urban	SMR	Chalmers University of Technology, Sweden
Thomas von Clarmann	MIPAS	Karlsruhe Institute of Technology, Germany
Kaley A. Walker	ACE-FTS	University of Toronto, Canada
Ray Wang	SAGE/HALOE	Georgia Institute of Technology, USA

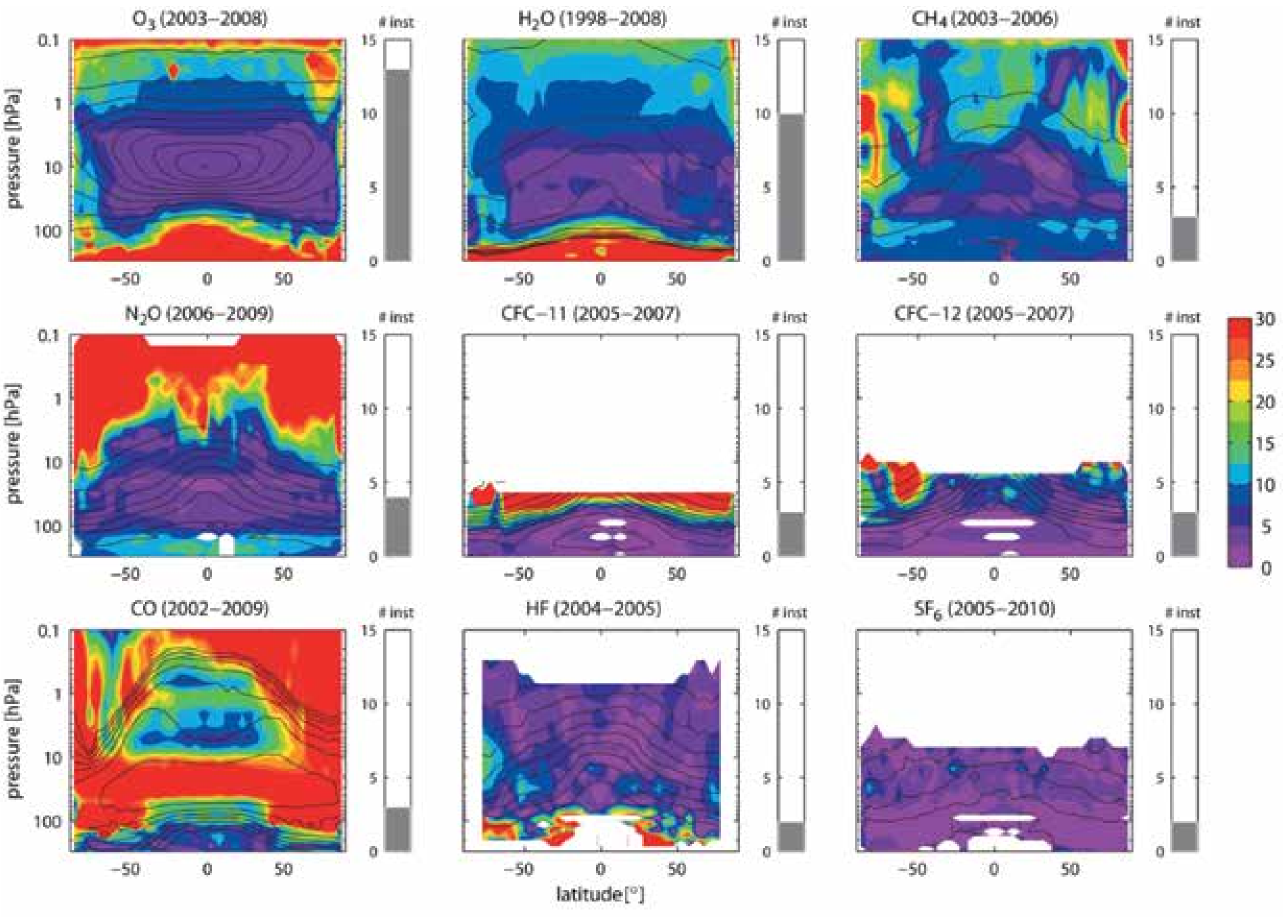

Figure 2: *Synopsis of uncertainty in the annual zonal mean state of longer-lived species. The relative standard deviation over all instruments' multi-annual zonal mean datasets is presented for O_3, H_2O, CH_4, N_2O, CFC-11, CFC-12, CO, HF, and SF_6 (color contours). The black contour lines represent the multi-instrument mean trace gas distribution for each species. The number of instruments included is given by the right-hand grey bar.*

activity to the International Space Science Institute (ISSI) in Bern, Switzerland. Two week-long workshops at the ISSI allowed for intensive and productive discussions on the advantages and drawbacks of the climatological evaluation approach of the SPARC Data Initiative. Bringing together data analysts and different instrument teams helped to explore many relevant questions such as the influence of *a priori* on climatologies, the impact of interpolation in altitude, and the terminology and ambiguousness of error terms. Some topics such as the impact of instrument sampling patterns, of averaging kernels, and averaging techniques were further investigated as part of the Data Initiative activities. Based on the expertise of the team, valuable information on general topics such as satellite orbits, observation geometries and measurement techniques, and specific descriptions of the participating instruments and retrieval versions were collected. During this phase, all chemical trace gas and aerosol monthly zonal-mean time series were also compiled in a common and simple-to-use NetCDF data format. Overall, the strong support and combined efforts of the SPARC Data Initiative team allowed fast progress of the activity within its first phase.

During its second phase in 2012-2013, the SPARC Date Initiative carried out detailed comparisons of ozone (Tegtmeier *et al.*, 2013) and water vapour (Hegglin *et al.*, 2013), as well as other longer-lived trace gases such as N_2O, CH_4, CO, SF_6, HF, CFC-11, CFC-12, HNO_3, and NO_y. The comparisons identified strengths and shortcomings of all datasets and differences between them. By evaluating monthly zonal-mean averages, the SPARC Data Initiative followed a new climatological approach to data validation with the advantages of being consistent for all instrument comparisons, avoiding sensitivities to chosen coincidence criteria, and generally producing larger sample sizes. The SPARC Data Initiative team developed an estimate of the uncertainty of the trace gas mean state derived from the inter-instrument spread of $\pm 1\sigma$. The uncertainty estimates are given as synopsis plots (see **Figure 2** for longer-lived gases) and helps to identify species and regions where further investigations or more data are needed.

The climatological approach has the disadvantage that monthly and annual zonal mean climatologies may be biased due to non-uniform sampling. This effect was investigated by estimating the impact of each instrument's sampling patterns on ozone and water vapour climatologies yielding useful information for studies of variability and trends and for comparisons with free-running models (Toohey *et al.*, 2013). Furthermore, the impact of averaging kernels in the upper troposphere/lower stratosphere region was investigated by smoothing observations of the higher vertical resolution limb sounders with the TES observational operator (Neu *et al.*, 2014). The results of the overall comparisons were discussed and approved during review meetings in Toronto, Canada, and Granada, Spain, to which a sub-set of reviewers of the work were invited each time.

During its final phase in 2014-2016, the SPARC Data Initiative completed the evaluations of all short-lived species such as NO, NO_2, NO_x, HCl, ClO, BrO, CH_2O, and aerosol. These comparisons werecomplicated by the strong diurnal cycles of these trace gases as well as wavelength dependencies of the aerosol extinction retrieval products. Different approaches for comparisons of the short-lived trace gases and the aerosol products are explored in the SPARC Data Initiative report resulting in uncertainty estimates of the shorter-lived nitrogen- und halogen-containing gases. Results of the comparisons have important implications for data analysis, trend evaluations, merging exercises, and model-measurement comparisons. With regard to the latter, the SPARC Data Initiative developed improved model evaluation diagnostics that are supported by a well-defined and small observational uncertainty.

All analyses, comparisons, and implications resulting from the SPARC Data Initiative have been published in the report making it the most up-to-date comprehensive assessment of stratospheric constituent observations. The report was produced with tremendous support from the SPARC offices in Toronto (Diane Pendlebury) and Zurich (Petra Bratfisch and Carolin Arndt), for which the SPARC Data Initiative Team is most grateful. We thank all contributing authors and reviewers for their continued support over the past years. We also thank WCRP and the different space agencies for their financial support for travel funding and in-kind support. One final word – this SPARC activity was a great experience that has formed the foundation for many strong collaborations. The SPARC Data Initiative report is dedicated to the memory of our friend and colleague Joachim Urban whose contribution and commitment were essential to this work.

References

Hegglin, M., *et al.*, 2013: SPARC Data Initiative: Comparison of water vapor climatologies from international satellite limb sounders. *J. Geophys. Res.-Atmos.*, **118**, 11824-11846, doi:10.1002/jgrd.50752

Neu, J., *et al.*, 2014: The SPARC Data Initiative: Comparison of upper troposphere/lower stratosphere ozone climatologies from limb-viewing instruments and the nadir-viewing Tropospheric Emission Spectrometer. J. *Geophys. Res.-Atmos.*, **119**, 6971-6990, doi: 10.1002/2013JD020822.

Tegtmeier, S., *et al.*, 2013: SPARC Data Initiative: A comparison of ozone climatologies from international satellite limb sounders. *J. Geophys. Res. Atmos.*, **118**, 12229–12247, doi:10.1002/2013JD019877.

Toohey, M., *et al.*, 2013: Characterizing sampling biases in the trace gas climatologies of the SPARC Data Initiative. *J. Geophys. Res.-Atmos.*, **118**, 11847– 11862, doi:10.1002/jgrd.50874.

Fine-Scale Atmospheric Processes and Structures

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High vertical-resolution radiosonde data (HVRRD) are radiosonde data saved at the native radiosonde resolution, which is on the order of seconds and corresponds to vertical-resolutions of metres (since the balloon rise rate is about 5m/s). These data provide valuable information on fine atmospheric structures and processes in such diverse areas as gravity waves, atmospheric turbulence, tropopause structure, and atmospheric boundary layer depth, among other uses. Some of the research on these subjects is briefly discussed, as is the desirability of increasing research access to HVRRD. One of the purposes of this paper is to introduce FISAPS, a new SPARC activity, and to solicit broader participation in the FISAPS activity.

This article can be viewed as a follow-up and expansion of two earlier papers, Love and Geller (2012, 2013) and also as a companion to the recent paper by Ingleby *et al*. (2016), which spoke to the operational uses of HVRRD. The Love and Geller (2012, 2013) papers discussed the scientific use of HVRRD, and the need to expand access to these data worldwide. In particular, Love and Geller (2013) highlighted a proposed new WCRP/SPARC activity on fine-scale atmospheric processes. FISAPS has now become a full SPARC activity, and this review article on scientific uses of HVRRD is written to serve as an introduction to FISAPS and its goals.

There are several justifications for the FISAPS activity within SPARC. One is historical. Hamilton and Vincent (1995) detailed SPARC's interest in making HVRRD generally available to the worldwide scientific community for gravity wave and other research, and the SPARC Data Centre has made US HVRRD generally available since 1998. HVRRD have proven to be very valuable for gravity wave research, and many papers on this research area have been written using HVRRD obtained from the SPARC Data Centre. These data have also been used for research in several other areas, some of which will be discussed in this article.

The atmosphere, being a non-linear system, shows a cascade of energy to higher (and lower) wavenumber motions until at very high wavenumbers dissipation occurs. Much of the turbulence occurring in the stable stratosphere occurs through wave breaking, as the amplitudes of gravity waves propagate to higher altitudes where the density is much less than the atmospheric levels where the gravity waves had their origin. This also occurs as gravity waves approach critical levels, where their phase velocity is equal to the wind velocity. Understanding the origin of atmospheric turbulent layers is important both scientifically and for better prediction of atmospheric turbulence for aviation operations.

Another motivation for research using HVRRD is to study atmospheric phenomena that show sharp transitions in altitude, some examples being the tropopause and the top of the atmospheric boundary layer. Also, aircraft and balloon observations have shown relatively thin structures in atmospheric chemical composition, and these thin structures need to be related to atmospheric motions through stirring and mixing. Accounting for these thin structures might very well be important for properly calculating chemical reaction rates in the atmosphere.

Examples of Previous Studies Using HVRRD

In the following, previous research utilising HVRRD is briefly presented. The discussion is organised around individual research topics.

Gravity Wave Research

This is the research area that initially motivated SPARC to set up an HVRRD initiative (see Allen and Vincent, 1995; and Hamilton and Vincent, 1995). It also motivated SPARC to initiate archiving of US HVRRD data in the SPARC Data Centre. There have been many papers on gravity waves that utilised the US HVRRD. Two interesting results (from among many) that have been derived from these data are illustrated in figures 1 and 2 from Wang and Geller (2003) and Wang *et al.* (2005), respectively. **Figure 3** shows that there is little correlation between the time series for total gravity wave energy in the troposphere and that in the lower stratosphere. In fact, the correlation between these time series for the entire year of 1998 was found to be 0.15, which is insignificant at the 95% level. Wang and Geller (2003) also showed that there was little correlation between the spatial distribution of tropospheric total gravity wave energy and that in the lower stratosphere.

Figure 4 shows several things. One is that the gravity waves in this HVRRD analysis are low frequency gravity waves with intrinsic frequencies of a few times the local Coriolis frequency. Another is that lower frequency waves are seen in the lower stratosphere than in the troposphere. The characteristic vertical wavelengths are 2-3km in both the troposphere and in the lower stratosphere. The lower stratospheric vertical wavelengths show a clear decrease with increasing latitude while the tropospheric vertical wavelengths are approximately constant between 10-50°N and decrease sharply at latitudes higher than 50°N. Longer horizontal wavelength waves are seen in the lower stratosphere than in the troposphere, and these horizontal wavelengths show a clear decrease as latitude increases. Finally, a much greater fraction of the gravity waves show upward energy propagation in the lower stratosphere than in the troposphere.

Interestingly, Wang *et al.* (2010) basically repeated the calculations of Wang and Geller (2003) for 10 years rather than for four years. The authors of Wang *et al.* (2010) are from China, but they analysed US radiosonde data rather than Chinese radiosonde data. Increased access to HRRVD worldwide is a subject we will return to toward the end of this article.

Atmospheric Turbulence

Clayson and Kantha (2008) showed that 6-second data (30m vertical resolution, assuming a balloon rise speed of 5m/s) HVRRD might be adequate for deriving turbulence parameters in the troposphere, but that at least 1-second data (corresponding to about 5m vertical resolution) is required to derive similar turbulence information in the stratosphere. The concept is as follows: Measurement of temperature and pressure allows construction of a potential temperature (θ) profile. Such a profile almost surely will contain some unstable layers where $\partial\theta/\partial z < 0$. The procedure then consists of sorting the θ values in the vertical so that the profile becomes at least neutrally stable at all altitudes, *i.e.*, $\partial\theta/\partial z \geq 0$. The local vertical distance necessary for this sorting is d', the Thorpe displacement. Now, $L_T=(d'^2)^{1/2}$, where L_T is the Thorpe length scale and the bracket indicates averaging over the altitude interval of instability over which the sorting is made. The turbulence energy dissipation rate ε can be computed using the formula $\varepsilon = N^3 L^2_O$, where N is the Brunt-Vaisälä frequency, and L_O is the Ozmidov length scale, which is the largest length scale of turbulent eddies not affected by stable stratification. L_O is not directly observable using radiosonde data, so Clayson and Kantha (2008) used the relationship $L_O = CL_T$ from Dillon (1982). Clayson and Kantha (2008) adopted a value of C = 0.8, while Dillon (1982) used C = 0.55. Of course, a balloon rising through the atmosphere encounters turbulent layers at various stages of development and initiated by different physical processes, so one would not expect $L_O = CL_T$ to be a universal relationship applicable to individual layers encountered by a rising balloon. On the other hand, there is some evidence from both turbulence observations and modelling to suggest that the linear relationship between the Ozmidov and Thorpe length scales is valid with sufficient averaging. For instance, **Figure 5a** shows a histogram for the relationship between L_O and L_T from LITOS (Leibniz Institute Turbulence Observations in the Stratosphere) measurements, while **Figure 5b** shows the relationship of the domain average ratio of L_O to L_T as a function of time from the Direct Numerical Simulations (DNS) of Fritts *et al.* (2016). Note that the histogram in Figure 5a indicates that for this particular balloon sounding, the most probable value for C^2 was approximately 0.1 and thus C for this flight is somewhere between 0.3 and 0.4. Schneider *et al.* (2015) also showed a similar histogram for a different balloon flight, BEXUS 12, which gave similar results for the average value for C. Examining Figure 5b, we see that the computational domain averaged value for C over the region delineated by the red line is on the order of 0.5-0.6. From these results, we conclude that, with suitable averaging, the Dillon (1982) relationship, $L_O = CL_T$, should be valid to within about a factor of two. Further support for this conclusion is seen in **Figure 6**, which combines results derived from the data used in Schneider *et al.* (2015), Love and Geller

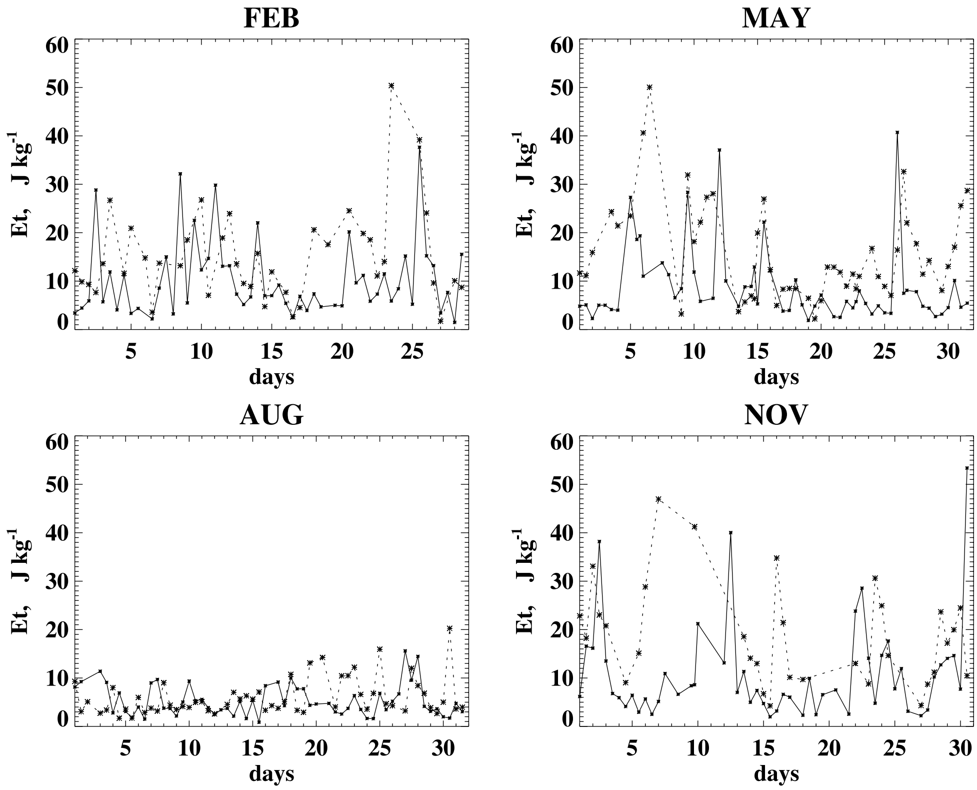


***Figure 3**:Time series of tropospheric total gravity wave energy density (solid lines) versus lower stratospheric total gravity wave energy (dotted lines) over Norman, Oklahoma (35.2 °N, 262.5 °E), during four months (February, May, August, November) of 2008. From Wang and Geller (2003).*

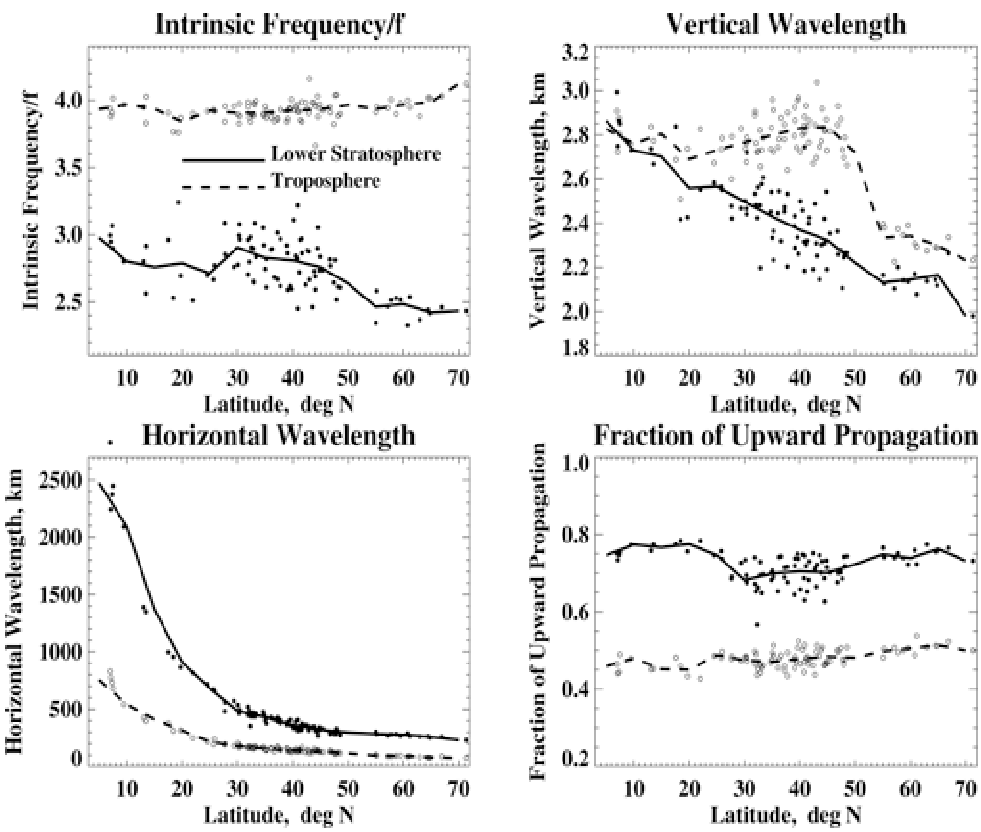


***Figure 4:** Five-year (1998-2002), averaged (top left) dominant intrinsic gravity wave frequency divided by the Coriolis frequency, (top right) dominant gravity wave vertical wavelength, (bottom left) dominant horizontal wavelength, and (bottom right) fractions of upward propagations as a function of latitude in the troposphere (open dots) and lower stratosphere (filled dots). The dashed and solid lines are the latitudinally binned results (with a bin size of 5°) for the troposphere and lower stratosphere, respectively. From Wang et al. (2005).*

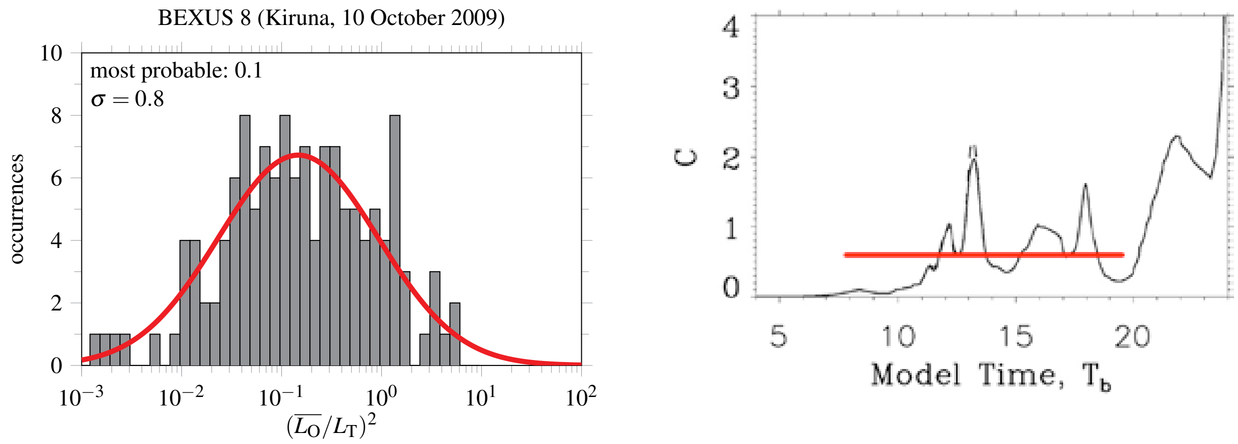


***Figure 5**: (left) Statistics for the ratio $(L_O/L_T)^2$ for LITOS measurements on the BEXUS 8 balloon flight (from Schneider et al., 2015), where the red curve is a best-fit log-normal curve. (right) Estimates for C = LO/LT from 4 to 24 T_B, where T_B is the undisturbed buoyancy oscillation period, for the full model computational domain using mean N^2, ε, L_O, and L_T for the DNS (Direct Numerical Simulation) results of Fritts et al. (2016), where the red line indicates approximately the conditions a rising balloon would be expected to encounter in determinations of L_T*

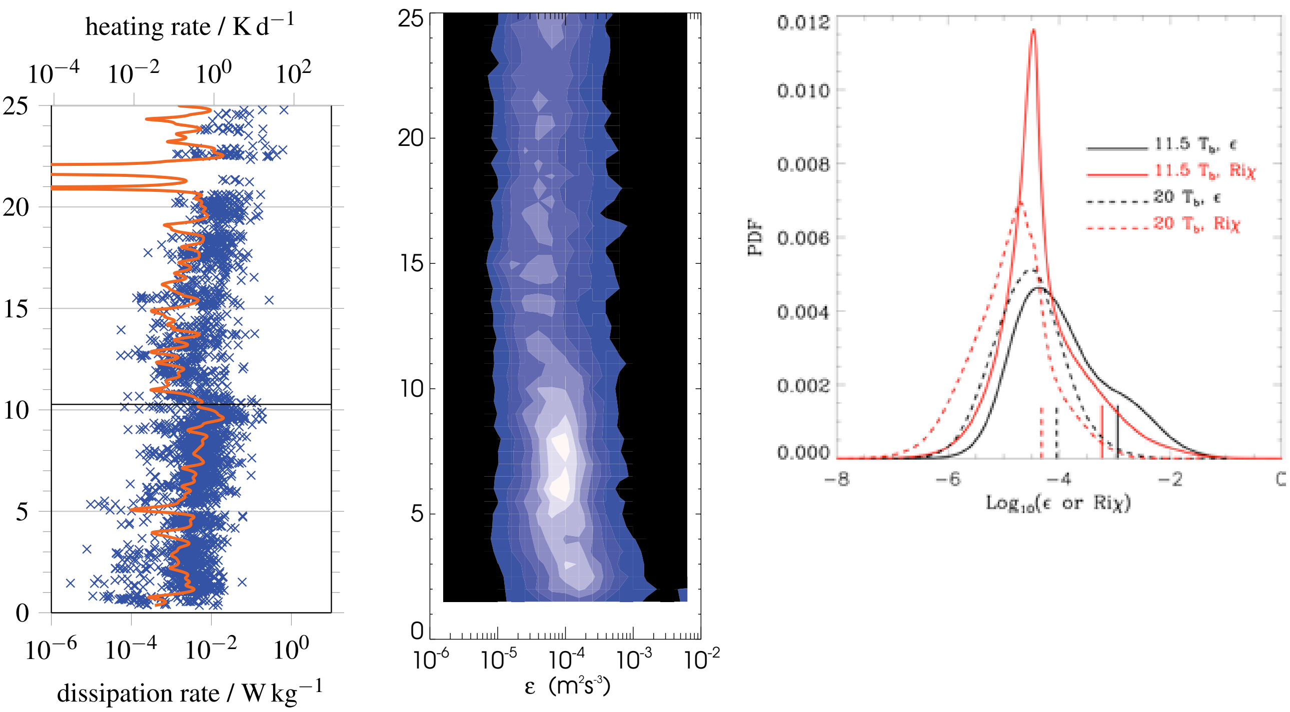


***Figure 6**: (left) Heating rate (in °K/day) and turbulent energy dissipation rate, ε in W/kg for the BEXUS 8 flight computed by spectral fitting as in Schneider et al. (2015), as a function of altitude (in km). (middle) Turbulent dissipation rate, ε derived from Thorpe analysis of Riverton, WY, radiosonde data for the winter of 2007 (from Love and Geller, 2012). (right) Turbulent energy dissipation rate computed directly from DNS results in Fritts et al. (2016) over their computational domain (black curves) for two different times during the simulation 11.5 T_B and 20 T_B, where T_B is the buoyancy oscillation period for the computational basic state.*

(2012), and from the modelling results of Fritts *et al.* (2016). Note that the three completely different methods agree with one another quite well. What remains to be determined is the degree of averaging needed to determine a stable relationship $L_O = CL_T$, so that quantitatively reliable averaged values of ε can be determined for scientific studies as well as for applications such as aviation turbulence.

Tropopause Studies

Birner *et al.* (2002) and Birner (2006) utilised German and US HVRRD to analyse the averaged fine structure of the tropopause. They developed a smart averaging technique in which radiosonde data were averaged, not with respect to the altitude above ground level, but rather with respect to the tropopause level. In this manner, they were able to preserve the fine structure of the tropopause (see **Figure 7**). The figure shows an inversion layer, where a distinct increase in temperature occurs at altitudes just above the tropopause, which is very sharp due to the averaging method. The average extra-tropical tropopause decreases in altitude as latitude increases. Furthermore, the layer over which the stability transitions from low tropospheric values to higher stratospheric values is narrower in altitude at lower latitudes.

Birner *et al.* (2002) and Birner (2006) motivated quite a bit of recent research. This includes a paper by Son and Polvani (2007), which showed that a tropopause inversion layer (TIL) structure could be simulated by a dry mechanistic model in which the troposphere is represented simply by relaxation to a baroclinically unstable radiative equilibrium state. Furthermore, they showed that the sharpness of the TIL seemed to depend more on increased horizontal resolution than on increased vertical resolution. They also showed that variability in the modelled tropopause altitude showed excellent correlation with the variability in upper tropospheric relative vorticity, consistent with the dynamics suggested by Wirth (2001). Bell and Geller (2008) made a more detailed investigation into the latitudinal and annual variation of the TIL. They considered the stability feature of the TIL to be fundamental to dynamics, and they coined the term ESTL, the extra-tropical stability transition layer, which is the depth of the region from the stability maximum to the region where $\partial N^2/\partial z = 0$, *i.e.*, from the cold-point tropopause to the altitude where it assumes normal stratospheric values, as a measure of tropopause sharpness. **Figure 8**, shows how the latitudinal variation of the ESTL varies throughout the year. Note that the tropopause is sharper at lower latitudes, and the curve of the latitudinal variation of the ESTL shifts about 15-20° poleward in June-August and September-November relative to December-March and March-May. Interestingly, Son and Polvani (2007) were able to simulate this when they varied the pole-to-equator difference in the radiative equilibrium troposphere to which they relaxed.

Considerable discussion has focused on the processes responsible for the sharpness of the TIL. Wirth (2001) suggested that the asymmetry in response of tropopause structure to upper tropospheric relative cyclonic and anticyclonic vorticity might be responsible for the sharp TIL. Randel *et al.* (2007) suggested that the sharp gradient in radiative cooling accompanying the sharp gradients in ozone and water vapour in the vicinity of the tropopause is likely an important sharpening mechanism. Birner (2010) suggested the importance of the Brewer-Dobson convergence of vertical velocity to be an important sharpening mechanism, and finally Wang and Geller (2016) suggested that baroclinic mixing of potential vorticity is the most important of the sharpening mechanisms.

One further note on this subject is that Bell and Geller (2008) showed that conventional radiosonde data could be used for many TIL studies due to their inclusion of significant levels, where the temperature gradients changed significantly, in addition to the low vertical-resolution mandatory levels. This is expanded upon in the next section.

High Vertical-Resolution Radiosonde Data as a Transfer Standard

US HVRRD have been freely available since 1998 (see **www.sparc-climate.org/data-center/data-access/us-radiosonde**). For many research purposes, longer time series of high-resolution radiosonde data are needed. Yuan *et al.* (2014) required a long series of HVRRD to derive the quasi-biennial oscillation (QBO) influence on temperature and winds in the vicinity of the tropical tropopause at a number of near-Equatorial stations. **Figure 9** shows comparisons between QBO easterly (in blue) and westerly (in red) wind (top) and temperature (bottom) profiles from 1998-2008 HVRRD (left) and the profiles from International

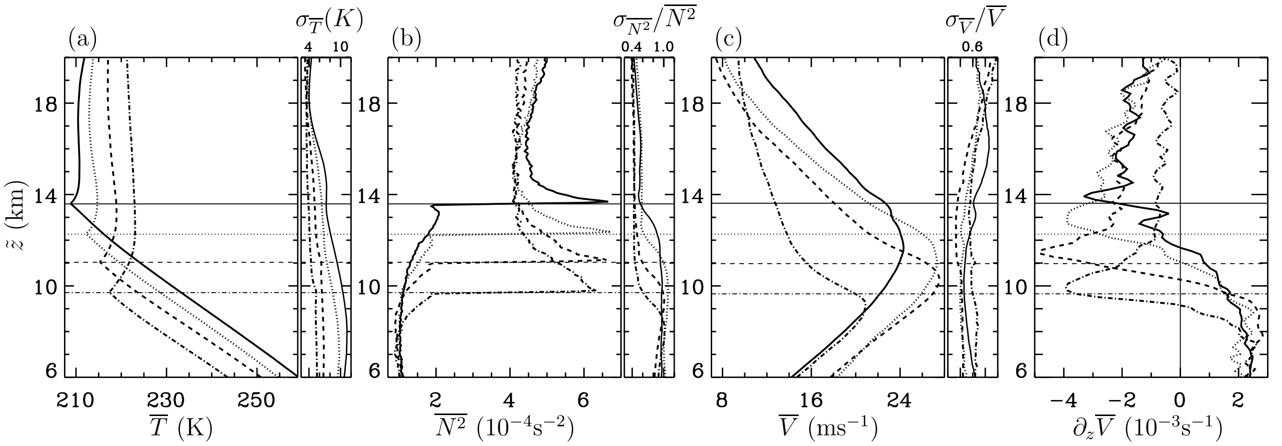
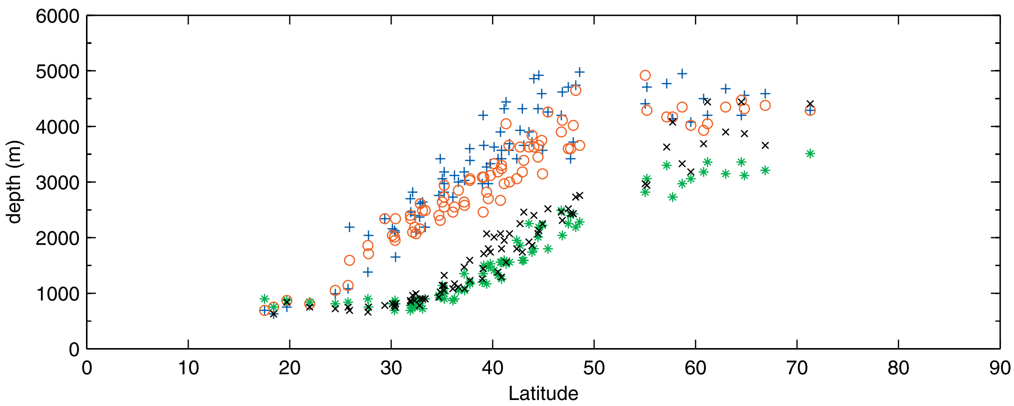


***Figure 7**: Annual climatologies for (a) temperature, (b) buoyancy frequency squared, (c) horizontal wind, and (d) the vertical shear of the horizontal wind for four West Coast stations: Miramar NAS, CA, - 33°N, 117°W (solid), Reno, NV, - 39.5°N, 119.5 °W (dotted), Quillayute, WA, - 48°N, 124.5°W (dashed) and Yakutat, AK, - 59.5°N, 139.7°W (dash-dotted) with horizontal lines denoting the tropopause height for each respective station. (Figure 5, from Birner, 2006).*

***Figure 8**: Seasonally-averaged latitudinal variability of the ESTL depths for high-resolution data for DJF (blue pluses), MAM (red circles), JJA (green asterisks) and SON (black crosses). From Bell and Geller (2008).*



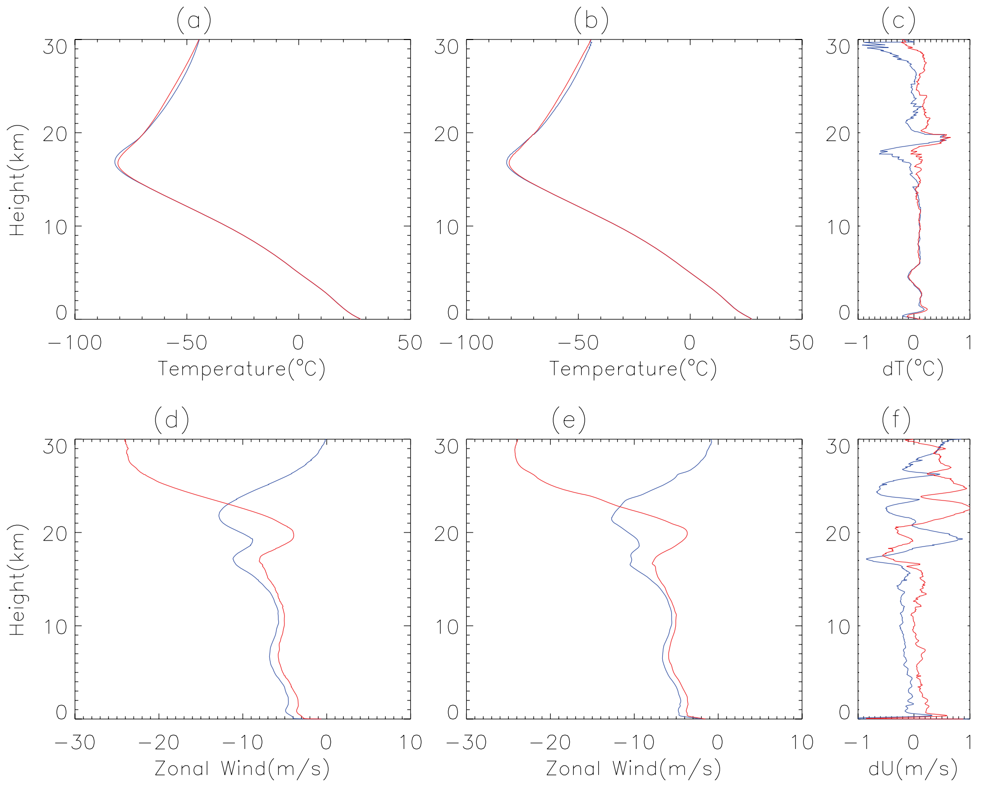


***Figure 9**: Comparison of composite QBO easterly (blue) and westerly (red) temperature profiles (top) and zonal wind profiles (bottom) using high vertical-resolution radiosonde data (left) and IGRA data (right) for the years 1998–2008 at Yap Island (9.48°N, 138.08°E). The right column shows (c) the temperature and (f) zonal wind differences between HRES/IGRA. The data were composited using a 6-month phase lag according to the wind shear at 50hPa. From Yuan et al. (2014).*

Global Radiosonde Archive (IGRA) data, using the methods of Bell and Geller (2008) to simulate high-resolution radiosonde data, from Yap Island (9.5°N, 138°E). Note that there are significant QBO-easterly to QBO-westerly zonal wind differences in the troposphere, which led us to believe that likely ENSO (El Niño-Southern Oscillation) effects were not sufficiently eliminated. In comparison, **Figure 10** shows the same QBO-easterly/QBO-westerly wind separation for Ponape Island when 60 years of IGRA data (using the Bell and Geller (2008) techniques) were used. Note that in Figure 10, no significant tropospheric wind differences are seen between QBO-easterly and QBO-westerly conditions, leading us to believe that ENSO effects have been effectively eliminated by the use of the longer dataset.

This example shows how comparison between HVRRD and IGRA data can be used to validate using long time series IGRA data to examine QBO and ENSO effects on winds and temperatures.

Other Scientific Studies Using High Vertical-Resolution Radiosonde Data

HVRRD were used by Folkins and Martin (2005) to characterise the vertical structure of tropical convection and the influence of this convection on the water vapour and ozone budgets. They were also used in the study of pyrocumulonimbus convective clouds by Fromm *et al.* (2010), and Seidel *et al.* (2012) showed that using HVRRD instead of conventional radiosonde data considerably reduced uncertainties in their analysis of the climatology of the planetary boundary layer.

Need for Increased Access to HVRRD

The US HVRRD, available for the period 1998-2011, have been archived at the SPARC Data Centre with 6-second resolution (corresponding to approximately 30m vertical resolution), but in 2005, a transition from the 6-second MicroART data to the 1-second Radiosonde Replacement System (RRS) data took place. Data at 1-second resolution for all stations from the beginning of the RRS program in 2005 to the present are now available directly from NOAA's National Centers for Environmental Information at **ftp://ftp.ncdc.noaa.gov/pub/data/ua/rrs-data**. MicroART data at 6-second resolution from 1998 until the time of transition to RRS for each station are available at **ftp://ftp.ncdc.noaa.gov/pub/data/ua/data/6-sec**.

The US radiosonde stations cover the continental US, Alaska, Hawaii, and a number of Pacific and Caribbean islands (see **www.sparc-climate.org/data-center/data-access/us-radiosonde**).

HVRRD are also available for a number of UK stations through the British Atmospheric Data Centre (BADC), see **http://catalogue.ceda.ac.uk/uuid/c1e2240c353f8edeb98087e90e6d832e**. Interestingly, a number of stations send real-time HVRRD data (mostly 2-second data from Europe and Australia) via the World Meteorological Organisation's Global Telecommunications System (WMO GTS) to forecast centres including the European Centre for Medium Range Forecasts (ECMWF).

For instance, **Figure 11** shows a world map of BUFR radiosonde reports for December 2016 (courtesy of Bruce Ingleby). This should be compared to Figure 6 of Ingleby *et al.* (2016), which showed the situation for December 2015. Note the improvement in the situation in one year. The percentage of stations reporting over 3000 data points has improved from 11% to 15% of reporting stations, with high-resolution data from Korea and New Zealand now being reported. The HVRRD coverage in the WMO GTS is expected to improve in the future, with the expectation of increased high-resolution data from the United States and Russia in the next year or so (Ingleby, personal communication). Forecast centres cannot use the full vertical resolution but can benefit from associated precision and metadata improvements. Note the following two quotes from Ingleby *et al.* (2016): "The impact of radiosonde data is expected to increase further once the reporting of the complete time and position information as well as high vertical resolution have been widely adopted and utilised in assimilation." and "We would encourage data producers to work towards high resolution BUFR data as soon as possible and to notify users in good time of such changes." As these high-resolution data become increasingly available for real-time forecasting, it will be desirable to archive them in a form where they can also be used for research purposes.

Fine-scale Structures in Chemical Constituents

Thin filamentary structures are also often seen in measurements of atmospheric composition. For instance, **Figure 12** shows measurements of ozone,

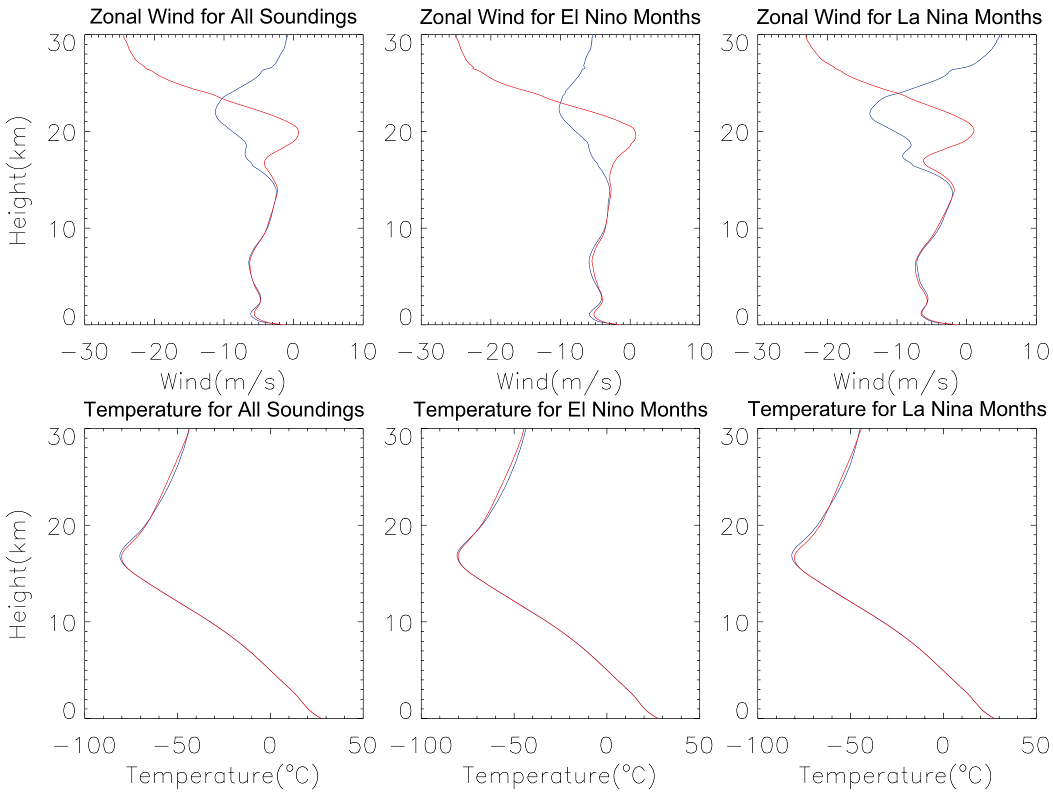


Figure 10: *The QBO variations in (top) zonal wind and (bottom) temperature difference for all (left) ENSO phases, (centre) El Niño and (right) La Niña conditions for Ponape (7.0°N, 158.2°E). The blue curves correspond to QBO easterly conditions, and the red curves to QBO westerly conditions. The data were composited using a 6-month phase lag according to the wind shear at 50hPa. The units of zonal wind and temperature difference are m/s and °C. From Yuan (2015).*

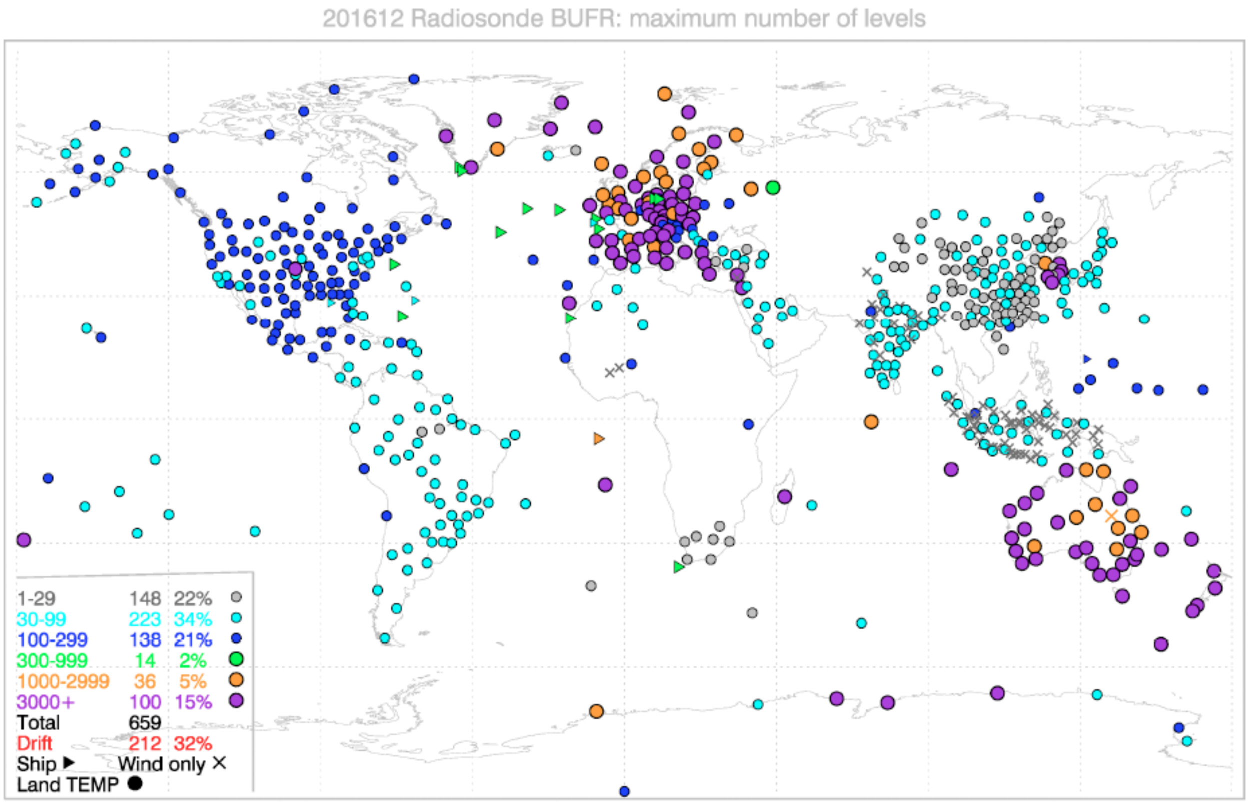


Figure 11*: Summary of BUFR radiosonde reports for 1-31 December 2016 decoded at the UK MetOffice, plotted by station. The colour indicates the maximum number of levels per report (grey 1-29, light blue 30-99, dark blue 100-299, green 300-999, orange 1000-2999, purple 3000 or more; the percentages in the key are relative to the number of stations plotted). Courtesy of Bruce Ingleby.*

Peroxyacyl Nitrate (PAN), and nitric acid taken by the CRISTA-NF infrared limb sounder flown on the Russian M55-Geophysica. These structures appear to be the result of differential advection or stripping of high stratospheric potential vorticity (PV) into the upper troposphere (see Wang and Geller, 2016, for example). These vertically thin structures are not seen in conventional chemical-transport models, but may be important for atmospheric chemistry.

For instance, the chemical reaction:

$$[A]+[B]\rightarrow[AB]$$

where A and B are two different chemical constituents reacting to produce the constituent AB, where the brackets indicate average constituent concentrations over a model grid box could be more accurately written as:

$$[[A]+A']+[[B]+B']\rightarrow[AB]$$

the primes denoting variations within the grid box), in which case the reaction rate would be:

$$k[([A]+A')([B]+B')]=k([A][B]+[A'B'])$$

Thus, inclusion of the small-scale constituent structures could be important for atmospheric chemistry.

FISAPS

SPARC recently approved FISAPS as a SPARC activity (see **www.sparc-climate.org/activities/fine-scale-processes** and Geller *et al.*, 2016). The present review paper is one of FISAPS' initial activities.

Initially, FISAPS is dynamically oriented, and its stated purpose is to utilise operational HVRRD and other sounding data to study phenomena that influence large-scale dynamics, but occur on vertical scales of less than one kilometre. These phenomena clearly include those discussed earlier in this article. One of the main FISAPS goals is to improve the archiving of these data so that more are available to the worldwide research community. With recent improvements to the vertical resolution of GPS radio occultation soundings, GPS data will also be valuable for this activity, as will aircraft and other

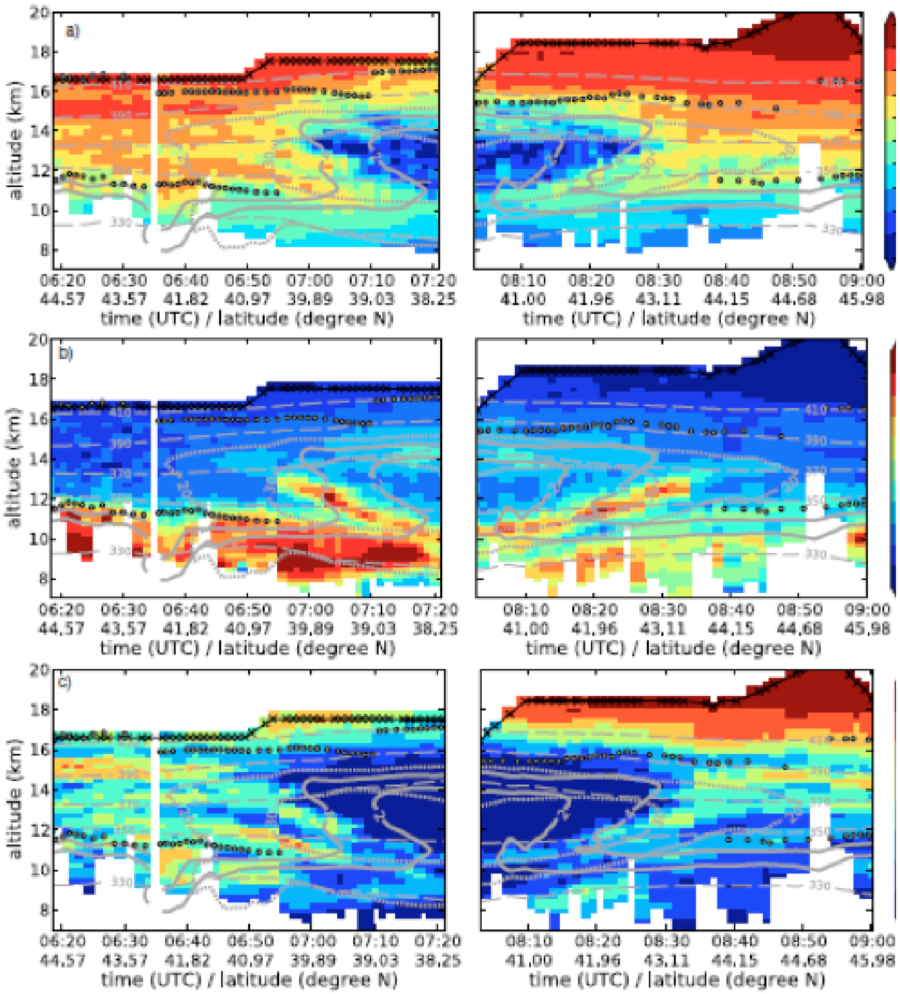


***Figure 12**: Retrieved cross-sections of (a) O_3, (b) PAN, and (c) HNO_3. The left cross-section shows the results of the western measurements and the right cross-section shows correspondingly the result of the eastward pointing measurements. Retrieved volume mixing ratios are depicted by coloured boxes. A discrete, non-linear colour scale was chosen to better highlight filamentary structures. The axes shows time of measurement and latitude at 12km altitude. The altitude of M55-Geophysica at the time of measurement is indicated as a solid black line with crosses marking the time of successively measured profiles. The position of primary and secondary lapse-rate tropopause are indicated by thick gray dots. The dotted gray lines show horizontal ECMWF wind speeds of 20 and 30m/s. The thick grey contour lines show ECMWF potential vorticity of 2 and 4 PVU.*

observations.

FISAPS' objective is to realise the full potential of large volumes of HVRRD archived worldwide. Providing coordination for the growing community of HVRRD users will promote the development of innovative applications of HVRRD by facilitating the sharing of expertise on analysis techniques, data handling, and technical capabilities and limitations. This sharing of expertise will be of similar benefit for the refinement and improvement of existing fields of research using HVRRD. Due to restrictions on access to HVRRD, previous studies have been limited to relatively small geographic coverage. This activity aims to address this limitation by two means, first, by coordinating broader regional intercomparisons and global studies that bring together researchers from the global HVRRD community. The second is to provide improved access to HVRRD to the research community.

Another important aspect of FISAPS is to involve the growing number of modelling groups who are modelling fine-scale structures in the atmosphere (*e.g.*, Fritts *et al.,* 2016). Using these modelling results, together with both operational and research observations of fine-scale structures in the atmosphere should lead to better analysis and interpretation of the observations.

While the initial focus of FISAPS will be on fine-scale dynamical structures, it is anticipated that FISAPS may expand its scope to fine-scale constituent structures and processes. As shown previously in this article, it is clear that tropospheric and stratospheric observations of atmospheric constituents show considerable fine structure, yet chemistry-transport models display relatively smooth structures. Quantifying how the absence of fine-scale structures in modelled chemical constituents affects computed chemical reaction rates would be a focus of this expanded activity. We urge all members of the scientific community with an interest in FISAPS science to express their interest to the authors of this article so that you may be contacted for future FISAPS activities.

References

Bell, S. W., and M. A. Geller, 2008: Tropopause inversion layer: Seasonal and latitudinal variations and representation in standard radiosonde data and global models. *J. Geophys. Res.*, **113**, D05109, doi:10.1029/2007JD009022.

Birner, T., 2006: Fine-scale structure of the extratropical tropopause region. *J. of Geophys. Res.*, **111**, D04,104, doi:10.1029/2005JD006,301.

Birner, T., A. Dornbrack, and U. Schumann, 2002: How sharp is the tropopause at midlatitudes? *Geophys. Res. Lett.,* **29**, 1700, doi:10.1029/2002GL015,142.

Birner, T., 2010: Residual Circulation and Tropopause Structure. *J. Atmos. Sci.,* **67**, 2582-2600.

Clayson, C. A., and L. Kantha, 2008: On turbulence and mixing in the free atmosphere inferred from high-resolution soundings. *J. Atmos. Ocean. Tech.*, **25**(6), 833-852, doi:10.1175/2007JTECHA992.1.

Dillon, T. M., 1982: Vertical overturns: A comparison of Thorpe and Ozmidov length scales. *J. Geophys. Res.*, **87**(C12), 9601–9613, doi:10.1029/JC087iC12p09601.

Folkins, I., and R. V. Martin, 2005: The Vertical Structure of Tropical Convection and Its Impact on the Budgets of Water Vapor and Ozone. *J. Atmos. Sci.,* **62**, 1560-1573.

Fritts, D. C., *et al.*, 2016: Numerical Modeling of Multi-Scale Dynamics at a High Reynolds Number: Instabilities, Turbulence, and an Assessment of Ozmidov and Thorpe Scales. *J. Atmos. Sci.,* **73**, doi: 10.1175/JAS-D-14-0343.1.

Fromm, M., *et al.*, 2010: The Untold Story of Pyrocumulonimbus. *Bull. Amer. Met. Soc.*, **91**(9), 1193-1209, doi:10.1175/2010BAMS3004.1.

Geller, M. A., H.-Y. Chun, and P. T. Love, 2016: FISAPS – An Emerging SPARC Activity. *SPARC Newsletter*, **47**, 8-10.

Hamilton, K., and R. A. Vincent, 1995: High-resolution radiosonde data offer new prospects for research. *Eos Trans. AGU,* **76**(*49*), 497, doi:10.1029/95EO00308.

Ingleby, B., *et al.*, 2016: Progress towards high-resolution, real-time radiosonde reports. *Bull. Amer. Met. Soc.*, **97**, 2149-2161, doi:10.1175/BAMS-D-15-00169.1.

Love, P. T., and M. A. Geller, 2012: Research using high (and higher) resolution radiosonde data. *Eos Trans. AGU,* **93**(35), 337.

Love, P. T. and M. A. Geller, 2013: Exploring and Improving Access to High Vertical Resolution Radiosonde Data. *Eos Trans. AGU,* **94**(44), 401.

Randel, W. J., F. Wu and P. Forster, 2007: The extratropical tropopause inversion layer: global observations with GPS data,

and a radiative forcing mechanism. J. Atmos. Sci., 64, 4489-4496.
Schneider, A., M. Gerding, and F.-J. Lübken, 2015: Comparing turbulent parameters obtained from LITOS and radiosonde measurements. *Atmos. Chem. Phys.*, **15**, 2159–2166, doi:10.5194/acp-15-2159-2015.

Seidel, D. J., C. O. Ao, and K. Li, 2010: Estimating climatological planetary boundary layer heights from radiosonde observations: Comparison of methods and uncertainty analysis. *J. Geophys. Res.*, **115**, D16113, doi:10.1029/2009JD013680.

Son, S.-W., and L. M. Polvani, 2007: Dynamical formation of an extra-tropical tropopause inversion layer in a relatively simple general circulation model. *Geophys. Res. Lett.*, **34**, L17806, doi:10.1029/2007GL030564.

Ungermann, J., 2013: Improving retrieval quality for airborne limb sounders by horizontal regularization. *Atmos. Meas. Tech.*, **6**, 15–32, doi:10.5194/amt-6-15-2013.

Wang, L., and M. A. Geller, 2003: Morphology of gravity-wave energy as observed from 4 years (1998–2001) of high vertical resolution U.S. radiosonde data. *J. Geophys. Res.*, **108**, 4489, doi:10.1029/2002JD002786, D16.
Wang, L., M. A. Geller, and M. J. Alexander, 2005: Spatial and Temporal Variations of Gravity Wave Parameters. Part I: Intrinsic Frequency, Wavelength, and Vertical Propagation Direction. *J. Atmos. Sci.*, **62**, 125–142. doi: 10.1175/JAS-3364.1.

Wang, R., S. D. Zhang, and F. Yi, 2010: Radiosonde observations of high-latitude planetary waves in the lower atmosphere. *Sci. China Ser. D*, **53** (6), 919–932, doi:10.1007/s11430-010-0069-0.

Wirth, V., 2001: Cyclone-Anticyclone asymmetry concerning the height of the thermal and the dynamical tropopause. *J. Atmos. Sci.*, **58**, 26-37.

Yuan, W., 2015: ENSO modulation of the QBO, and QBO influence on tropical convection. *PhD dissertation, Stony Brook University*, 149 pp.

Yuan, W., M. A. Geller, and P. T. Love, 2014: ENSO Influence on QBO Modulations of the Tropical Tropopause. *Q. J. Roy. Meteorol. Soc.*, **140**, 1670-1676, DOI: 10.1002/qj.2247, 2014.

The Polar Climate Predictability Initiative

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The Polar Climate Predictability Initiative (PCPI) is an initiative of the World Climate Research Programme (WCRP) core projects CliC (Climate and Cryosphere) and SPARC. The PCPI aims to advance understanding of the sources of polar climate predictability on timescales ranging from seasonal to multi-decadal. Such predictability stems from the unique persistence of signals in ice and snow, as well as through exchange with the stratosphere and with the ocean at all depths. PCPI is concerned with the success of modelling and observing the rapid changes seen in the Arctic and the mixed, slow and fast changes occurring in the Antarctic. PCPI is investigating the role of the poles in global climate and prediction. We work jointly with the World Weather Research Programme's Polar Prediction Project (WWRP - PPP) on mutual interests, though our focus tends towards longer timescales. PCPI also collaborates with the WCRP's Grand Challenge on Near Term Climate Prediction. PCPI maintains links with many other groups that have mutual interests, including ASPeCt (Antarctic Sea ice Processes and Climate), SORP (Southern Ocean Research Panel), SIPN (Sea Ice Prediction Network - South) and the Scientific Committee for Antarctic Research's (SCAR) AntClim21.

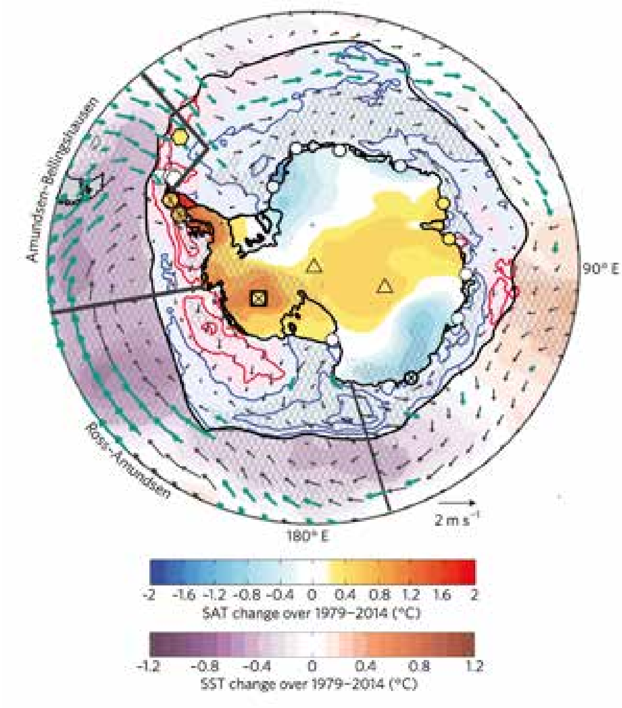


Figure 13*: Antarctic climate system trends in the instrumental record period. These trends were found to be typical of variability in Antarctic paleoclimate records of the past two centuries, while most climate model simulations are incompatible with these observations. (Jones, et al, 2016).*

Recent activities

In 2016 we held a Spring School on Polar Prediction for 30 post-graduate and early career researchers at the Abisko Field Station in Sweden in collaboration with PPP. PCPI also organised three workshops on: Polar Prediction (with PPP), Polar Feedbacks, and Sea Ice Thickness. We published one review paper on recent trends in the Southern Ocean (Jones *et al.*, 2016; see **Figure 13**) which is the outcome of a workshop held the year before. We published another paper on the Amundsen Sea Low (Raphael *et al.*, 2016), also the outcome of a PCPI workshop. A third paper, an intercomparison of the sensitivity of predictions to initial sea ice thickness (Blanchard-Wrigglesworth *et al*, 2016) was also published. Several PCPI sessions were also hosted at AGU and EGU on Polar Prediction and at AGU on Data Assimilation Products. In March 2017 a follow-on workshop to the 2016 Polar Prediction workshop (also joint with PPP), was held at the Alfred Wegener Institute, in Bremerhaven, Germany. It focused on decadal variability and was held synchronously with CliC's Sea Ice MIP Workshop.

Future Plans

PCPI will participate in AntClim21's #GreatAntarcticClimateHack Workshop (held from 9-12 October 2017) and continues to work on the WCRP Grand Challenge on Near-Term Climate Prediction. A review paper that evolved from our 2016 workshop on climate feedbacks is also in final review by the 14 authors, led by Hugues Goosse and Jennifer Kay. PCPI is undergoing a change in leadership as co-lead Cecilia Bitz stepped down in early 2016 and is being replaced by Julie Jones. Cecilia Bitz and Ted Shepherd were the first leaders of PCPI. A meeting of co-leads Julie Jones and Marilyn Raphael to discuss future plans for PCPI will occur in July 2017. We encourage those interested in PCPI activities to visit the website at **www.climate-cryosphere.org/wcrp/pcpi** and/or contact us: **Marilyn Raphael** (raphael@geog.ucla.edu) or **Julie Jones** (julie.jones@sheffield.ac.uk)

References

Jones, J. M., *et al.*, 2016: Assessing recent trends in high-latitude Southern Hemisphere surface climate, *Nature Climate Change*, **6,** 917-926, doi:10.1038/NCLIMATE3103.

Blanchard-Wrigglesworth, E., *et al.*, 2016: Multi-model seasonal forecast of Arctic sea-ice forecast uncertainty at pan-Arctic and regional scales, *Climate Dynamics,* doi:10.1007/s00382-016-3388-9.

Raphael, M.N, *et al.*, 2016. The Amundsen Sea Low: variability, change, and impact on Antarctic climate, *Bulletin of the American Meteorological Society,* **97** (1), 111-121. doi: 10.1175/BAMS-D-14-00018.1

WAVAS-II Annual Meeting

Karen Rosenlof[1], Gabriele Stiller[2], and Stefan Lossow[2]

[1]Chemical Sciences Division, NOAA, Boulder, Colorado, USA, (**karen.h.rosenlof@noaa.gov**), [2]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

DATES:
30 November – 2 December 2016

ORGANISER:
Gabriele Stiller, Karlsruhe Institute of Technology (KIT)

HOST INSTITUTION:
KIT, Karlsruhe, Germany

NUMBER OF PARTICIPANTS: 11

SPONSORS:

Karlsruher Institut für Technologie

BACKGROUND:
Following phase I of the Water Vapour (WAVAS) activity, which analysed and assessed long-term changes of Upper Tropospheric and Stratospheric (UTS) water vapour from *in situ* datasets from hygrometers and remote sensing instruments, the WAVAS-II activity aims to assess the value and accuracy of recent satellite measurements and to give new recommendations and guidelines for future research on UTS water vapour.

ACTIVITY WEBSITE:
www.sparc-climate.org/activities/water-vapour

In 2000 SPARC published its Assessment of Upper Tropospheric and Stratospheric (UTS) Water Vapour (SPARC Report No. 2, available at **www.sparc-climate.org/publications/sparc-reports/sparc-report-no2**), which was coordinated and edited by Dieter Kley, James M. Russell III, and Celine Phillips. The key topic addressed in this report was the analysis and assessment of long-term changes of UTS water vapour, with an emphasis on the observed increase of water vapour in the stratosphere. The report had a strong focus on describing and comparing relevant datasets using *in situ* hygrometers and remote sensing instruments from laboratories around the world to create a suitable long-term dataset, including historical data back to the 1940s.

In the years since, climatological measurement programmes have continued, new campaigns to investigate UTS water vapour have been carried out, new satellite observation programmes have been launched, and many model and laboratory studies have explained the observations and identified previously unknown processes. Detection of trends has become an important climate issue and for such analyses it is critical to have well verified estimates of possible instrument drifts. To understand microphysical processes related to water vapour, knowing the absolute accuracy and not simply the relative discrepancies between different sensors is important. The primary goal of the WAVAS-II activity is to assess the value and accuracy of recent satellite measurements and to give new recommendations and guidelines for future research on UTS water vapour.

The objectives of WAVAS-II are to:

1. Provide a quality assessment of upper tropospheric to lower mesospheric satellite records since 2000;
2. Provide, as far as possible, absolute validation against ground-truth instruments;
3. Assess inter-instrument biases, depending on altitude, location, and season;
4. Assess representation of temporal variations on various scales;
5. Include data records on isotopologues;
6. Provide recommendations for use of available data records and for future observation systems.

This is the first effort to compare all available stratospheric satellite water vapour profiles with research-quality balloon- and ground-based measurements of water vapour. The results are being prepared for publication in a special issue of ACP/AMT/ESSD (**www.atmos-chem-phys.net/special_issue830.html**) where WAVAS-II and related independent papers will be published.

The core author team of the WAVAS-II satellite comparison activity met at the Institute of Meteorology and Climate Research of the Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany, for a three-day working session to advance the papers on the assessment of the quality of water vapour records from satellite instruments. During the meeting, results from the planned papers were presented and open issues related to consistency amongst the papers were discussed.. On the last day, Maarit Lockhoff from the GEWEX G-VAP activity joined the group to exchange details about the assessment methods used and to discuss future opportunities for joint activities between GEWEX and SPARC.

Presentations were given for each major component of the report, each of which will be submitted as a paper to the journal special issue.

Discussions started with the characterisation paper (**Kaley Walker** and **Gabriele Stiller**), which will describe all measurements used in the WAVAS-II activity. This will include descriptions of the techniques used as well as information on temporal/spatial coverage, vertical resolution, precision, systematic errors, and recommended data filtering. The satellite instruments and periods for which they were or will continue to be active are shown in **Figure 13**.

The second paper will compare all available frost point hygrometer profiles with satellite profiles. **Michael Kiefer** and **Dale Hurst** presented statistics for profile-to-profile comparisons between seven frost point stations and 15 satellites. Dale also discussed the method he used to determine drifts between satellite data records and the time series' from frost point hygrometer stations. This method is to be applied to all satellite instruments and stations with long enough data records.

Gerald Nedoluha and **Michael Kiefer** presented their work on the comparison of upper stratospheric and mesospheric water vapour profiles between satellite records and ground-based microwave radiometer data (Nedoluha *et al.*, 2017). Both biases and drifts were presented. **Stefan Lossow** discussed results that will be covered in two WAVAS-II papers. One paper will present satellite-to-satellite comparisons, both on the basis of co-incident profiles and for zonal means. Another paper, which has subsequently been published in the WAVAS-II special issue (Lossow *et al.*, 2017), presents an analysis of the available time series using multivariate linear regression and compares several derived quantities such as the amplitude and phase of the seasonal cycle as well as other oscillations among the various datasets.

The sixth paper under preparation, presented by **Farah Khosrawi**, will cover the biases and drifts between the various satellite datasets, and the ability of the satellite data records to reproduce intra- and inter-annual variability. The latter will be done on the basis of correlation analyses among the time series.

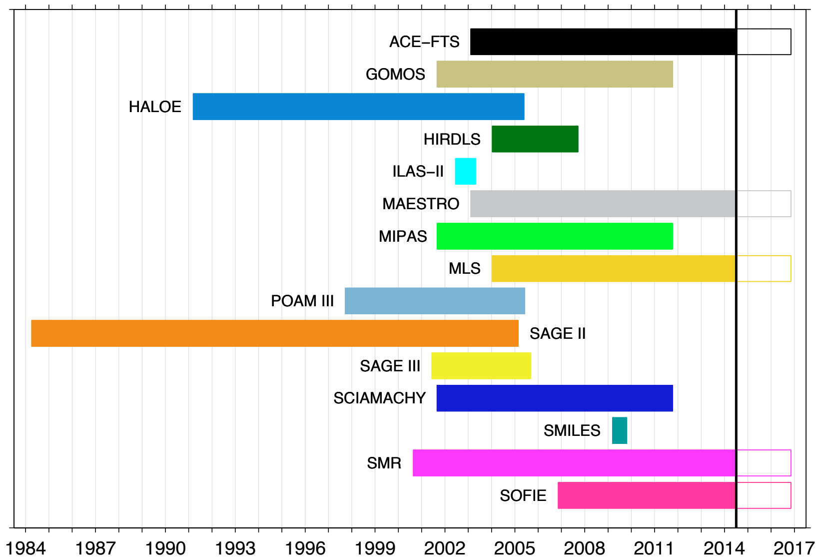
A seventh paper, presented by **William Read**, will focus on upper tropospheric humidity (measurements taken below the local tropopause). He showed results comparing satellite profiles with frost point hygrometer and radiosonde data. Additionally, he showed a correlation analysis with profiles from meteorological sounders (AIRS and TES) and compared gridded satellite data on pressure levels.

Two further papers under preparation, presented by **Kaley Walker** and **Stefan Lossow** respectively , will show comparisons of data records of minor water vapour isotopologues HDO, $H_2{}^{18}O$, and $H_2{}^{17}O$ that are measured by ACE-FTS, SMR, and MIPAS (only HDO from MIPAS). Comparisons of the related isotopic ratios $\delta D\text{-}H_2O$, $\delta^{18}O\text{-}H_2O$, and $\delta^{17}O\text{-}H_2O$ will also be included.

The final discussion, led by **Karen Rosenlof** and **John Gille**, covered what will go into the summary and recommendations paper that will be prepared after completion of the comparison papers mentioned above.

A follow-up meeting took place in June 2017 at the University of Toronto, hosted by Kaley Walker. This was hopefully the last meeting before finalising this activity. This will effectively close the WAVAS circle, as the first WAVAS-II meeting also took place in Toronto, in March 2009.

Figure 13: *Satellite measurements considered in the stratospheric comparisons of the WAVAS-II activity. Tropospheric comparisons will include additional satellite measurements from TOVS, AIRS, IASI, and TES.*



References

Lossow *et al.*, 2017: The SPARC water vapour assessment II: comparison of annual, semi-annual and quasi-biennial variations in stratospheric and lower mesospheric water vapour observed from satellites. *Atmos. Meas. Tech.*, **10**, 1111-1137, doi:10.5194/amt-10-1111-2017.

Nedoluha, *et al.*:, 2017: The SPARC water vapor assessment II: intercomparison of satellite and ground-based microwave measurements. *Atmos. Chem. Phys.* Discuss., doi:10.5194/acp-2017-578.

Figure 15: *WAVAS-II core author team during the working group meeting held from 30 November to 2 December 2016 at KIT, Karlsruhe, Germany.*

SSiRC Meeting at ISSI

Larry Thomason[1] and Stefanie Kremser[2]

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DATES:
30 January – 2 February 2017

ORGANISERS:
Larry Thomason (NASA, USA), Claudia Timmreck (Max Planck Institute for Meteorology, Germany), Stefanie Kremser (Bodeker Scientific, New Zealand), and Jean-Paul Vernier (SSAI, USA)

HOST INSTITUTION:
International SpaceScience Institute (ISSI), Bern, Switzerland

NUMBER OF PARTICIPANTS: 12

SPONSORS:

BACKGROUND:
SSiRC is focused on understanding the role of sulphur and particularly sulphate aerosol in climate processes. SSiRC as an International Team (SSiRC_IT) held its first meeting at ISSI in Bern, Switzerland, from 30 January to 2 February 2017. This meeting also served as a SSiRC Science Steering Group (SSG) meeting.

ACTIVITY WEBSITE:
www.sparc-climate.org/activities/stratospheric-sulfur

Stratospheric Sulfur and its Role in Climate (SSiRC) is a SPARC activity and has been supported by the International Space Science Institute (ISSI). ISSI support was recently renewed and the first meeting of the international team, SSiRC_IT, was held at the ISSI facility in Bern, Switzerland, from 30 January to 2 February 2017. The SSiRC Science Steering Group (SSG) has undergone some changes recently. Markus Rex has stepped down from the leadership team while remaining on the SSG. Graham Mann (UK) and Suvarna Fadnavis (India) recently joined the SSiRC SSG.

SSiRC_IT helped in the past to formulate the SPARC SSiRC activity and was key to the production of the Review of Geophysics paper on stratospheric sulfur (Kremser *et al.*, 2016). The new SSiRC_IT is focused on a subset of SPARC SSiRC activities, including efforts to: 1) Assess and advocate for the ability to forecast likely climate impacts following a major volcanic eruption. This includes identifying key activities required ahead of a major eruption, and promoting activities designed to improve historical observation-based stratospheric aerosol datasets; 2) Estimate the measured stratospheric sulfur burden (both gas-phase and aerosol); and 3) Leverage the relatively modest contribution of volcanic activity to the stratospheric burden over the past decade to assess non-volcanic aerosol and aerosol precursor levels, transport, and microphysical processes. This effort is focused on the upper troposphere/lower stratosphere (UT/LS) and how these factors are represented in climate models. Ultimately, SSiRC remains focused on investigations that improve our understanding of the feedback between stratospheric aerosol and climate, by developing tools to improve aerosol representation in climate models and investigating how a changing climate affects non-volcanic stratospheric sulfur sources and their transport. SSiRC has cooperated with a number of other SPARC activities such as the CCMI (Chemistry-Climate Model Initiative). In future, we foresee interactions with emerging activities such as OCTAV-UTLS (Observed Composition Trends and Variability in the Upper Troposphere and Lower Stratosphere) and TUNER (Towards Unified Error Reporting). Parties interested in SSiRC activities can join the SSiRC community email list (which currently has about 240 members) at **https://listserv.gwdg.de/mailman/listinfo/ssirc**.

SSiRC is in the process of developing two meetings. A proposal for an American Geophysical Union (AGU) Chapman

Conference has been accepted and this meeting will be focused on the role of aerosol during volcanically quiescent periods; a topic motivated by an extended period (1999 to the present) where stratospheric aerosol have been at or near the lowest levels observed by modern instrumentation. The conveners are Terry Deshler, Larry Thomason, and Mian Chin and the meeting will take place in March 2018 in Tenerife, Spain. SSiRC is also sponsoring a workshop on stratospheric aerosol measurements focused on facilitating communications and collaborations among scientists responsible for observations of stratospheric aerosol using *in situ*, ground-, and space-based instruments. Key goals are to develop strategies for understanding and reducing differences among instruments, and for characterising the continuity of the measurement record as instruments and measurement paradigms change. The end goal for the workshop is to facilitate providing data users, particularly the climate modelling community, more robust and better-characterised datasets than normally obtained from single instruments. The workshop is scheduled for 6-8 September 2017 in Boulder, Colorado. See the SPARC SSiRC webpage for further information.

Jean-Paul Vernier and **Claudia Timmreck** are leading the SSiRC Volcanic Response Plan (or VolRes) effort to produce a blueprint for how the scientific community should respond to a new large volcanic eruption, should one happen in future. The primary objective is to facilitate the ability of climate scientists to predict climate impacts of such a major eruption, so that they can provide robust estimates to national and international organisations. The products will consist of an assessment of readiness and what is needed to characterise such an eruption in detail, as well as a website that would coordinate sharing data following the event. The goal is to submit the document for publication by mid-2017. The SSiRC ISSI team suggested interacting with people involved in a similar NASA-organised activity to avoid duplication of effort. More than 100 members of the SSiRC community indicated interest in this effort and more than 30 are actively involved in producing the white paper on this topic.

The SSiRC Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP) is well under way. This project is focused on understanding how well interactive stratospheric aerosol models represent several key processes, including representation of the stratospheric aerosol layer during volcanically quiescent periods, the observed trend in stratospheric aerosol load since 2000, and the basic mechanisms driving variability in stratospheric aerosol levels.

Much of the ISSI team meeting consisted of talks focused on topics of key interest to SSiRC. For instance, **Claudia Timmreck** updated the team regarding the progress of the ongoing Model Intercomparison Project on the Climatic Response to Volcanic Forcing (VolMIP, Zanchettin *et al.*, 2016). VolMIP is a CMIP6-endorsed activity that defines a common protocol focused on multi-model assessment of climate model performance under strong volcanic forcing conditions. For this, VolMIP has defined a set of idealised volcanic perturbations based on historical eruptions using aerosol optical parameters from available observations. The experiments are ensemble simulations using initial climate states sampled from an unperturbed pre-industrial simulation. Recent evaluations of CMIP5 models suggest that most models correctly produce warm winters and reduced summer monsoon precipitation after large volcanic eruptions (**Alan Robock**). They also support the idea that volcanic eruptions increase the probability of an El Niño in the year following an eruption. Based on these evaluations, it appears likely that volcanic eruptions were necessary for the initiation and maintenance of the Little Ice Age by inducing a new Arctic sea-ice or ocean circulation state.

A key SSiRC activity is producing a historical record for stratospheric aerosol based on observations. For CMIP6 the record extends from 1850 to 2014 (updated from 1960 to 2012) and has undergone a number of improvements (**Larry Thomason**). These include a new treatment of high latitude

Figure 16*: The SSiRC ISSI Team during the team meeting in Bern, Switzerland.*

winter where observations are unavailable for much of the SAGE period (1979 to 2005). The Pinatubo gap in the SAGE II record is now primarily filled using CLAES, though issues remain unresolved for the first several months after the eruption. Substantial improvements have been made to the post-SAGE period, which is now based on a combination of OSIRIS and CALIPSO data. The CMIP5 dataset only used CALIPSO data equatorward of 50°. This lack of true polar data created several issues that have been rectified in the new CMIP6 version by using CALIPSO and OSIRIS data up to 80° in both hemispheres. Aerosol size distribution and radiative parameter data customised for a number of chemistry climate models (CCMs) have been created and delivered to the CMIP modelling groups (**Beiping Luo**). Several improvements have been made to the model used to retrieve these data, including avoiding the use of a weak SAGE II measurement at 386nm and using HALOE 3.40µm observations as a verification of the robustness of fits rather than as a constraint.

SSiRC is coordinating the first effort to estimate the stratospheric sulfur (gas and aerosol) burden based on measurements (**Terry Deshler**). The effort focuses on a compilation of all relevant measurements from 1979 onwards, which will necessarily be constrained to a limited number of sulfur-bearing gas species and aerosol. Particular emphasis will be placed on 2004/2005 when the essential measurements were nearly completely covered. These include measurements of sulfur dioxide (SO_2) by MIPAS and carbonyl sulfide (OCS) from several instruments. The result will provide valuable comparison opportunities for sulfur burdens estimated with climate models (*e.g.,* Sheng *et al.*, 2015). An important note is that there is an ongoing debate with respect to the tropospheric OCS budget. Results and hypotheses in recent publications are far from converging; resolving obvious discrepancies in quantifying the important OCS sources and sinks is an area of active research. This potentially has significant impacts on attempts to implement a process-based OCS flux into the stratosphere in climate models. Another source of aerosol, meteoric smoke particles (MSP), have the potential to contribute substantially to the production of condensation nuclei for sulfate aerosol in much of the stratosphere (**Graham Mann**). The winter poles are an area where the input of meteoritic material from the mesosphere (and above) is the highest. However, the inferred MSP mass flux at high latitudes is much smaller than would be expected based on current estimates of meteoritic input at the top of the atmosphere. This is also an area subject to active research.

Recent advances in the NCAR Community Earth System Model Community Aerosol and Radiation Model for Atmospheres (CESM/CARMA) component of the Whole Atmosphere Community Climate Model (WACCM) demonstrate how far the interactive modelling of aerosol within chemistry-climate models CCMs has progressed (**Pengfei Yu**). CARMA correctly represents stratospheric aerosol at the low levels observed since 2000 according to comparisons with ground- and space-based measurements. The model suggests that while even the background stratospheric aerosol is predominately sulfate, about 30% of the non-volcanic aerosol column mass is due to the presence of organic materials in the lower stratosphere. It also suggests that the Asian Tropopause Aerosol Layer (ATAL) accounts for about 15% of the non-volcanic stratospheric aerosol mass. CESM/CARMA allows the study of historic events such as the Laki eruption of 1783-1784, and simulations using this model suggest that while the warm summer of 1783 in Europe was caused by internal climate variability, it would have been even warmer without Laki (**Alan Robock**). Laki was also responsible for a negative North Atlantic Oscillation and El Niño in the boreal winter of 1783-1784 and responsible for large precipitation reductions in Africa and Asia with devastating impacts on local populations.

The long continuous *in situ* stratospheric aerosol dataset from the University of Wyoming has undergone one recent major revision (Kovilakam and Deshler, 2015) and is currently going through additional evaluations to more fully account for the counting efficiency problem identified by Kovilakam and Deshler. This affects the measurements since 1991 (**Terry Deshler**). The update is expected to be completed later in 2017. Improved agreement between the optical particle counter (OPC) and SAGE II suggests that leveraging *in situ* measurements to improve inferences of aerosol characteristics from space-based measurement systems is possible (**Larry Thomason**). Work on this topic is underway and a related SSiRC workshop should help illuminate the promise and issues related to this approach.

BATAL is a collaborative effort between NASA and several institutions in India and Saudi Arabia (**Jean-Paul Vernier**). Its primary goal is to understand the properties of the ATAL, its importance to climate, and its role in transport of anthropogenic material to the stratosphere. Funding for flights in 2017 and 2018 has been acquired and a new sonde site at Naintal, India, is well situated to support ATAL studies as well as the monsoonal circulation (**Suvarna Fadnavis**). Data taken during a pilot program in August 2016 showed that the monsoon anticyclone was dynamically active and played a role in the exchange of low latitude and extra-tropical air. Other campaigns are planned for August 2017 and 2018. These include flights into the monsoon anticyclone and ATAL with the high altitude (20km) M55-Geophysica research aircraft carrying a comprehensive aerosol, sulfur gas, and tracer payload that will be carried out as part of the EU StratoClim project. The main goals of these flights are to understand the dynamics of the anticyclone and to determine the microphysical and chemical properties of the ATAL.

A new measurement campaign, Strateole 2, promises a unique platform to investigate the Tropical Tropopause Layer (TTL) from long-duration balloons. The balloons will be confined to the equatorial layer, ±10° latitude, stay aloft for up to three months, and drift at altitudes of 18-20km. Measurements are planned to characterise fine scale gravity waves, infrared fluxes, aerosol size distribution, and the temperature, water vapour, and cloud structure across the TTL, between 16 and 18km. The gondolas at 20km will contain remote sensing instruments while the gondolas at 18km will contain *in situ* instruments. Of these a reel down platform will carry existing, proven, balloon-borne instruments: a COBALD for clouds, FLASH B for water vapour, and a temperature package. These instruments will provide ten profiles of cloud, water vapour, and temperature across the TTL each night. A 2 km-long optical fibre on another *in situ* gondola will provide continuous temperature profiles both day and night. Both of these measurements, along with all others, will extend for the duration of the gondola flights (2-3 months). Engineering test flights are planned in late 2018 and science flights from October 2020 to January 2021. A brief description of the campaign is provided at **www-das.uwyo.edu/~deshler/research/Strateole2**. Other SSiRC-relevant instrument developments include the new SAGE III mission that NASA launched on 19 February 2017 and that begun operations

Figure 17: *Balloon launch from the TFIR Balloon Facility in Hyderabad, India, during the BATAL 2015 campaign.*

on the International Space Station in April 2017 (**Larry Thomason**). Collaborative efforts form a key component for validation of this instrument (**https://sage.nasa.gov/missions/about-sage-iii-on-iss**). Finally, OSIRIS continues to operate after more than 15 years (**Landon Rieger**) and represents a key component of long-term stratospheric aerosol (and ozone) datasets.

References

Kremser, S., *et al.*, 2016: Stratospheric aerosol - Observations, processes, and impact on climate. *Rev. Geophys.*, **54,** 256-276, doi:10.1002/2015rg000511.

Kovilakam, M., and T. Deshler, 2015: On the accuracy of stratospheric aerosol extinction derived from *in situ* size distribution measurements and surface area density derived from remote SAGE II and HALOE extinction measurements. *J. Geophys. Res.*, **120**, 8426–8447, doi:10.1002/2015JD023303.

Sheng, J. X., *et al.*, 2015: Global atmospheric sulfur budget under volcanically quiescent conditions: Aerosol-chemistry-climate model predictions and validation. *J. Geophys. Res.-Atm.*, **120**, 256-276.

Timmreck, C., *et al.*, (subm.): The Interactive Stratospheric Aerosol Model Intercomparison Project (ISA-MIP): Motivation and experimental design. *Geosci. Model Dev.*

Zanchettin, D., *et al.*, 2016: The Model Intercomparison Project on the climatic response to Volcanic forcing (VolMIP): experimental design and forcing input data for CMIP6. *Geosci. Model Dev.,* **9**, 2701-2719, doi:10.5194/gmd-9-2701-2016.

SPARC LOTUS workshop report

Irina Petropavlovskikh[1], Daan Hubert[2], Sophie Godin-Beekman[3], Robert Damadeo[4], Birgit Hassler[5], and Viktoria Sofieva[6]

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DATES:
13 – 15 March 2017

ORGANISERS:
Sophie Godin-Beekmann (LATMOS, Université Pierre et Marie Curie, Paris, France), Daan Hubert (Royal Belgian Institute for Space Aeronomy, Brussels, Belgium), and Irina Petropavlovskikh (Global Monitoring Division, NOAA, Boulder, Colorado, USA)

HOST INSTITUTION:
LATMOS, Université Pierre et Marie Curie, Paris, France

NUMBER OF PARTICIPANTS: 30

SPONSORS:

BACKGROUND:
LOTUS (Long-term Ozone Trends and Uncertainties in the Stratosphere) is an international research initiative endorsed by SPARC and the International Ozone Commission. LOTUS aims to revisit the methods used to derive long-term vertically-resolved trends of stratospheric ozone and to improve our understanding of the uncertainty budget. This work will contribute significantly to the 2018 WMO/UNEP Ozone Assessment.

ACTIVITY WEBSITE:
www.sparc-climate.org/activities/ozone-trends

A first LOTUS workshop was organised by the coordinators of the initiative (Daan Hubert, Irina Petropavlovskikh, and Sophie Godin-Beekmann) and hosted by LATMOS at the Université Pierre et Marie Curie in Paris, France, from 13-15 March 2017. Thirty researchers attended this invite-only workshop and participated in a lively informal meeting with a selected number of scheduled oral presentations and ample time for discussions. An overview presentation about the needs for Chapter 3 of the upcoming WMO/UNEP Ozone Assessment by the lead authors supported the scope of the meeting and stressed the timeline of LOTUS. The workshop participants discussed the status of the activities of the two working groups: MIDI (production of observation time series) and ROAST (regression analyses of the time series).

During the MIDI session, we focused on results and plans of the assessment of quality and uncertainties of ozone profile time series made available to the LOTUS project by a number of participating satellite and/or ground-based instruments principal investigators. Several new ozone profile composites are being produced for use in the LOTUS project besides from recent updates and improvements to existing single or merged data records. In addition to improved long-term stability of satellite records in combined datasets, trend analyses can now rely on longer and more consistent measurement records. Several questions were addressed, such as the impact of changing sampling patterns, the impact of instrument drift and biases between instruments, as well as methods to obtain reliable estimates of relevant uncertainty in trend analyses. First results indicate clear improvements in the agreement between the time series of the different datasets, and some historical disagreements are now much better understood.

During the ROAST session we discussed the activities, first results, and plans of the working group focusing on the regression analyses of ozone profile time series. Participants interrogated currently available methods to determine a preferred set-up for regression models, ranging from what proxies to include, the use of a linear versus non-linear model, or whether to incorporate the uncertainty of observations in the regression or not. We agreed on the main options to explore further in the coming months. These sensitivity tests will inform us about the robustness of estimated trends and uncertainties against

***Figure 18**: Participants of the LOTUS workshop held at the Université Pierre et Marie Curie in Paris, France from 13-15 March 2017.*

alternative choices in the regression analysis. In addition, first results of a technical test of regression codes developed independently by twelve groups were presented. Consistent results were obtained in general for most regressed parameters, showing that there are no major flaws in any of the participating codes.

The workshop concluded with an interactive session to define the outline of the final LOTUS report, which will include – besides the results of the activities mentioned above – an identification of remaining open issues.

More detailed information on the LOTUS workshop can be found at: **https://events.oma.be/indico/event/23/overview**.

The Third Workshop on Atmospheric Composition and the Asian Monsoon (ACAM) and the Second ACAM Training School

Laura Pan[1], Jim Crawford[2], Xuemeing Wang[3], Jianchun Bian[4], Mary Barth[1], Ritesh Gautam[5], and Federico Fierli[6]

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DATES:
Workshop: 5-9 June 2017
Training School: 10-12 June 2017

ORGANISERS:
Scientific Organising Committee:
Laura Pann, Jim Crawford, Michelle Santee, Hiroshi Tanimoto, Arnico Panday, Vinayak Sinha, Gabi Stiller Jessica Neu, Chiara Cagnazzo, Mian Chin, Hans Schlager, Jianchun Bian, Mary Barth, Ritesh Gautam, Federico Fierli
Local Organising Committee:
Xuemei Wang, Jianchun Bian, Song Yang, Qi Fan, Jason Cohen, Hong Liao, Shaw Liu, Boguang Wang, Junyu Zheng, Sachiko Hayashida, Masatomo Fujiwara, Prabir Patra, Rokjin Park, Suresh Babu, Suvarna Fadnavis, and Manish Naja, Maheswar Rupakheti, Bhupesh Adhikary, Faheem Khokhar, Abdus Salam, Narisara Thongboonchoo, Kim Oanh, Mohd Talib Latif, Puji Lestari

HOST INSTITUTION:
Jinan University, Guangzhou, China

NUMBER OF PARTICIPANTS: 160

SPONSORS:

Following the first and second workshops in 2013 (Kathmandu, Nepal) and 2015 (Bangkok, Thailand), the ACAM community recently held its third workshop at Jinan University in Guangzhou, China, from 5-9 June 2017. The participants included 160 scientists from 18 different countries (**Figure 18**). The scientific discussion spanned issues ranging from ground-level air quality to upper atmospheric composition in the Asian monsoon region. The region is unique given the interaction between the monsoon meteorology and emissions from human activity where population and economic development are undergoing rapid change. These interactions have important local implications in terms of the coupling between pollution and monsoon changes and their impacts on human health and the regional economy. The interactions are also of global significance, since monsoon convection serves as an effective conduit for pollution to reach the upper atmosphere with potential impacts on climate and stratospheric ozone.

The scientific scope of the workshop followed the four ACAM scientific themes, each representing a key aspect of the connection between atmospheric composition and Asian monsoon dynamics:

1. Emissions and air quality in the Asian monsoon region. This theme spans all seasons, recognising issues ranging from summertime photochemical smog to winter pollution episodes.
2. Aerosols, clouds, and their interactions with the Asian monsoon. This theme recognises the dominant impact of aerosols on this region and the continuing exploration of evidence for feedbacks influencing the monsoon climate system.
3. Impact of monsoon convection on chemistry. This theme focuses on the vertical redistribution of anthropogenic and natural emissions, expanding the impact of Asian emissions on atmospheric chemistry globally.
4. Upper troposphere/lower stratosphere (UTLS) Response to the Asian Monsoon. This theme emphasises the intersection between Asian emissions and the monsoon anticyclone circulation as a conduit for increased anthropogenic influence on the UTLS environment.

SPONSORS:

BACKGROUND:

ACAM is a joint SPARC/IGAC activity that focuses on the connection between atmospheric composition and Asian monsoon dynamics. These interactions have important local implications and global impacts. The third ACAM workshop spanned issues ranging from ground-level air quality to upper atmospheric composition in the Asian monsoon region.

ACTIVITY WEBSITES:

www.sparc-climate.org/activities/asian-monsoon

www2.acom.ucar.edu/acam

Following the four themes, the attendees presented 80 talks and 50 posters on recent science results, as well as current and future plans for field observations in the region. Discussion sessions were devoted to a number of collaboration topics including data sharing, participation in community modelling efforts, coordination of field observations, and capacity building through training and mentoring of young scientists. Most of the presentations are posted on the third ACAM workshop page: **www2.acom.ucar.edu/acam/guangzhou-2017-agenda**

Following the workshop, ACAM held its second training school on 'Observations and Modelling of Atmospheric Chemistry and Aerosols in the Asian Monsoon' from 10-12 June at Jinan University. Specific goals of the training school were (1) to provide training for early career scientists on topics relevant to studying trace gases and aerosols in Asia, particularly in connection with the Asian monsoon; (2) to create a network of ACAM early career scientists; and (3) to provide resources for improving their science and communication skills. This event was the second in the series of training activities organised as part of the ACAM working group on capacity building, with the previous one conducted at the Asian Institute of Technology, Bangkok, Thailand, in June 2015.

Over 40 students and nine lecturers participated in the training school, representing seven Asian countries and three European countries, with over one third female participants. Participants were either current students (primarily graduate students) or early career researchers within three years of receiving their PhD, with interest in learning about observations and modelling tools for applications to ACAM research.

Lecturers at the school presented various topics including theoretical and practical information on their particular area of expertise. Lectures ranged from satellite remote sensing and aircraft observations, to global and regional modelling, but the main focus was on trace gases, aerosols, transport processes, and air-sea interactions in the Asian monsoon region. **Tianjun Zhou** presented two overview lectures on the Asian monsoon, associated air-sea interactions, and the role of anthropogenic forcings on Asian monsoon circulation patterns and rainfall variability in the region. **Jessica Neu** and **Ritesh Gautam** discussed satellite measurements and retrieval techniques for atmospheric composition measurements, while **Elliot Atlas** and **Sachin Ghude** presented methods used for sampling trace gases from aircraft and with ground-based instruments. **Chiara Cagnazzo**, **Federico Fierli**, **Mian Chin**, and **Mary Barth** discussed global and regional scale modelling, transport processes, and analysis of trace gases and aerosols in relation to the Asian region. Sachin Ghude also discussed emission inventories and their evaluation.

A highlight of the school was the "Science and Communication

Figure 19: *Participants of the third ACAM workshop held at Jinan University, Guanzhou, China, from 5-9 June 2017.*

Café", in which three major topics were addressed. The first was a discussion and exercise on communicating science to the general public in the form of a press release. Participants were exposed to methods for effectively translating research findings into non-technical and jargon-free language. The second topic discussed the significance of organisation of slides for oral presentations, for instance highlighting the logical balance between size, colours of text/figures, and the importance of ending a presentation with a summary/conclusion slide. The third topic was an exercise on creating a "science elevator speech"- a clear, brief message about a research finding and its broad significance in just a few minutes (akin to the time it takes for people to ride in an elevator from the bottom to the top of a building). These were all interactive exercises with group presentations of press releases by the participants.

Other hands-on activities included group tasks to propose an aircraft field campaign based on a topic relevant to ACAM, with the students determining the type of instruments needed to address the objectives of the field campaign, and the modelling framework to forecast and analyse the field campaign data. These hands-on activities created a collegial camaraderie among the participants and lecturers. The participants were enthusiastic about the "Science and Communications Café" as well as the hands-on activities, suggesting that more time be spent on these practical exercises. However, they also enjoyed the more theoretical lectures, which broadened their knowledge on various aspects related to observations and modelling.

The lectures have been posted on the ACAM 2nd Training School website: **www2.acom.ucar.edu/acam/guangzhou-2017-training-school**. Information about other training schools and resources in relation to ACAM are also available from the same website.

The workshop and training school were made possible by generous sponsorship from the following organisations that provided for meeting facilities and expenses, as well as travel support for 55 of the meeting attendees: China Association for Science and Technology (CAST), Chinese Academy of Sciences (CAS), Key Laboratory of Middle Atmosphere and Global Environment Observation (LAGEO), Nanjing University of Information Science and Technology (NUIST), Jinan University, International Commission on Atmospheric Chemistry and Global Pollution (iCACGP), Stratosphere-troposphere Processes And their Role in Climate (SPARC), International Global Atmospheric Chemistry project (IGAC), International Centre for Integrated Mountain Development (ICIMOD), Forschungszentrum Jülich, National Center for Atmospheric Research (NCAR), National Aeronautics and Space Administration (NASA), and Picarro Inc. Both the workshop and training school significantly benefited from the outstanding support of the local student volunteers at Jinan University.

Report on the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2017 Science Workshop

Michaela I. Hegglin[1], Bryan N. Duncan[2], Arlene M. Fiore[3], Gunnar Myhre[4], Tatsuya Nagashima[5], Fiona M. O'Connor[6], David A. Plummer[7], Seok-Woo Son[8], and Paul J. Young[9]

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DATES:
13-15 June 2017

ORGANISERS:
CCMI co-chairs, CCMI Scientific Steering Group, Béatrice Josse, Virginie Marécal, Martine Michou, Isabelle Varin, Jean Maziejewski, Philippe Caille

HOST INSTITUTION:
MétéoFrance, Toulouse, France

NUMBER OF PARTICIPANTS: 100

SPONSORS:

BACKGROUND:
CCMI is a joint SPARC/IGAC activity established to coordinate chemistry-climate model evaluation in an effort to increase our process-based understanding of tropospheric and stratospheric chemistry-climate interactions.. This is done through community-coordinated simulations and evaluations thereof using innovative methods and observations.

ACTIVITY WEBSITE:
www.sparc-climate.org/activities/ccm-initiative

The IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2017 Science Workshop was held from 13-15 June 2017 at MétéoFrance in Toulouse, France. The presentations and discussions focused on multi-model analyses associated with the IGAC/SPARC CCMI Community Simulations (Eyring *et al.*, 2013). The purpose of these simulations is to address emerging science questions in chemistry-climate modelling, improve process understanding, and support upcoming ozone and climate assessments. Details of the models participating in the CCMI Community Simulations effort are given in Morgenstern *et al.* (2017) and on the CCMI website. The agenda also included a number of invited speakers, who spoke on various topics relevant and complementary to CCMI efforts. The presentations were grouped by theme: links to other communities, the stratosphere, observations for model evaluation, stratosphere-troposphere coupling, tropospheric chemistry and dynamics, and finally an impact-oriented session with a focus on air quality. The oral sessions were complemented by three extended poster sessions, which provided ample time for discussion of exciting studies covering a range of topics related to chemistry-climate interactions, including both observational and modelling studies. Around 100 participants attended the workshop. **Alison Ming**, tweeted live from the workshop, sharing some of the excitement and science from the workshop with the wider CCMI community who were not able to attend. The tweets from the workshop are summarised in a Storify (see weblink on **http://blogs.reading.ac.uk/ccmi**). CCMI Scientific Steering Committee (SSC) meetings were held before and after the workshop.

CCMI and its Big Brothers

The workshop opened with a warm welcome by our French hosts, MétéoFrance (**Marc Pontaud** and **Béatrice Josse**), and an overview presentation on CCMI by **Michaela Hegglin**, who highlighted the purpose and status of the IGAC/SPARC-led international activity. These were followed by presentations from representatives of the parent organisations of CCMI, IGAC (**Colette Heald**) and SPARC (**Fiona Tummon**). Both highlighted the importance of CCMI to bring together a diverse range of scientists who work on scientific issues of an interdisciplinary nature. **Guy Brasseur**, current chair of the

WCRP Joint Scientific Committee and first keynote lecturer, shared his personal view of global change research. He started with highlighting the early achievements of individual climate scientists such as James Keeling, who started measuring CO_2 in the atmosphere, and Syukuro Manabe, who performed the first climate change model simulations with results that are still valid today. Their research raised awareness of global change problems and associated science questions that could only be addressed through international coordination of research efforts. This helped motivate the establishment of global observation and modelling systems. Subsequent developments led to the birth of WCRP and the International Geosphere-Biosphere Project (IGBP), whose responsibility is not only to guide the direction of fundamental research needed to address the grand challenges in global change research, but more recently also to connect with and serve the user community.

Links with Other Communities

This session kicked off with a second keynote lecture by **Didier Hauglustaine** on nitrate aerosol. Despite the importance of these aerosol for air quality, climate, and ecosystem health, there is a wide spread in column-integrated nitrate among models used within AeroCom. The differences are attributed to the representation of both wet and dry deposition processes, as well as to precursor gases, and the partitioning between fine- and coarse-mode aerosol. Interestingly, a reduction in nitrogen emissions in future might accelerate the decline in ocean productivity, given that over 50% of the oceans are nitrogen-limited. **Michael Schulz** (invited) then introduced AerChemMIP, the CMIP6 model intercomparison project focusing on quantifying the change in composition, forcings, feedbacks, and the global-to-regional climate response from changes in emissions of near-term climate forcers including aerosols, tropospheric ozone, nitrous oxide, methane, and ozone-depleting substances. Simulations using fixed sea surface temperatures will be used to derive effective radiative forcing and coupled transient experiments will aim to quantify the regional climate response. In particular, AerChemMIP aims to provide the first consistent documentation and quantification of forcings in CMIP models.

The next invited speaker was **Stefano Galmarini** who presented Phase 2 of the Hemispheric Transport of Air Pollution (HTAP-2) activity, and the Air Quality Modelling Evaluation International Initiative (AQMEII). Using an ensemble of global and regional models, the overarching aim of these international activities is to quantify source-receptor relationships and to use them to estimate the impact of future emission strategies. Efforts have also focused on model evaluation: Error decomposition and apportionment to different timescales was presented as a methodology for novel model evaluation.

Doug Kinnison (invited), presented an overview of the 2018 Assessment on Stratospheric Ozone Depletion. Key developments of the CCMI models since the last assessment were summarized to include ocean coupling, simulations with specified dynamics, representation of the quasi-biennial oscillation (QBO), and improved tropospheric and stratospheric chemistry. Initial analysis of the CCMI modelled past and future total column ozone shows good consistency with previous assessment results, but also highlighted the importance of documenting changes relative to the results obtained from the models used in the SPARC CCMVal-2 activity.

Finally, **Ramiro Checa-Garcia** presented the methodology used to generate a new CCMI ozone forcing dataset for use in CMIP6 climate model simulations that do not include interactive chemistry. The dataset is aimed at replacing and improving the Cionni *et al.* (2011) ozone forcing database produced for CMIP5. The ozone dataset is based on two chemistry-climate models (the NCAR CESM/WACCM and the Canadian CMAM), uses updated emissions, solar, and volcanic forcings, and covers the 1850-2100 time period.

Stratosphere

This session was mostly focused on stratospheric composition and transport in the CCMI historical (REF-C1) and the specified dynamics (REF-C1SD) simulations. The first speaker, **Luke Oman**, provided an overview of dynamical transport of stratospheric ozone and nitrous oxide (N_2O) associated with the Brewer-Dobson circulation, the QBO, and the El Niño-Southern Oscillation (ENSO) in CCMI models. Both REF-C1 (see **Figure 19**) and REF-C1SD runs successfully reproduced the chemical loss of late-spring Antarctic ozone and the dynamical enhancement of summertime upper-stratospheric ozone concentrations, although the

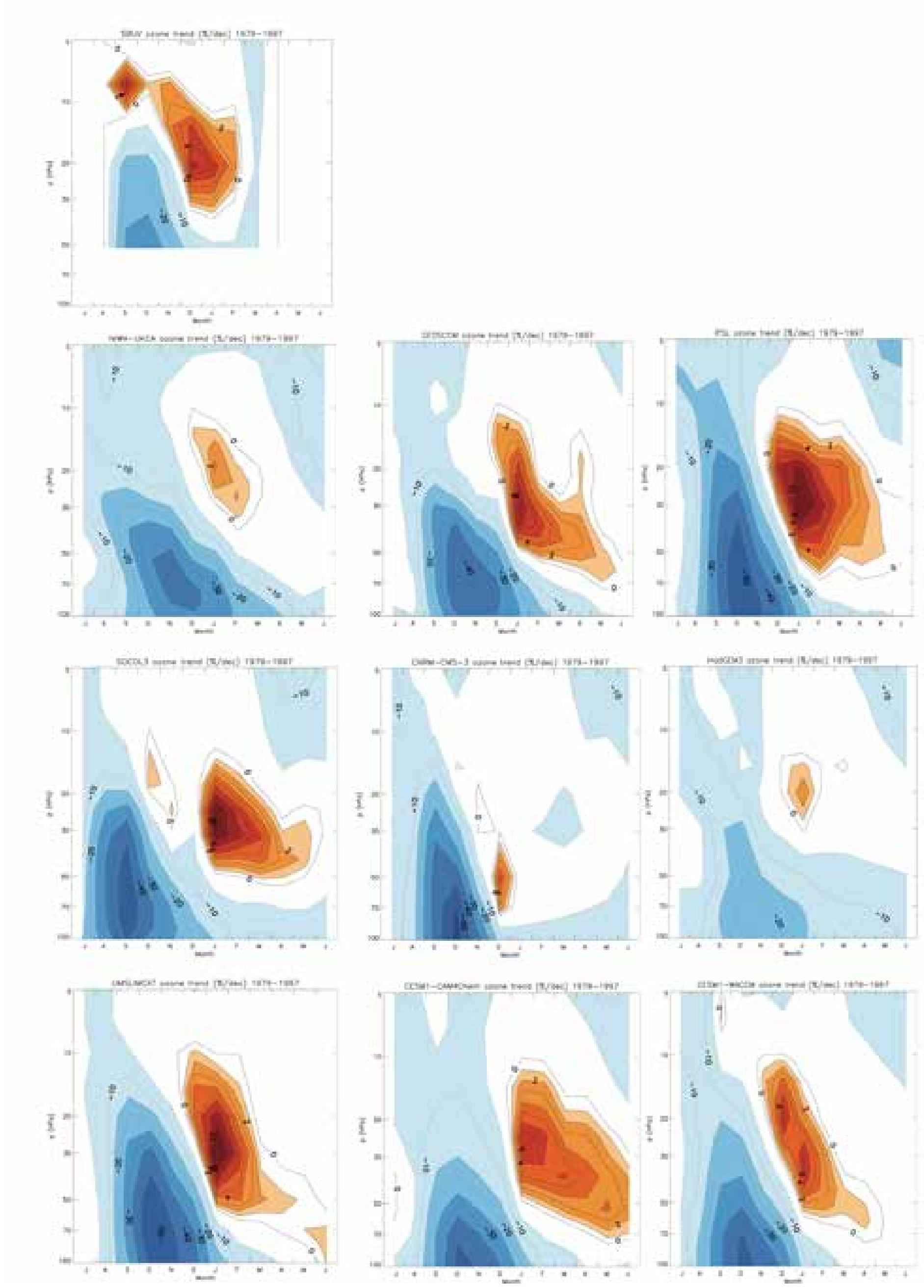

Figure 20*: REF-C1 simulations of the seasonal evolution of the Antarctic ozone hole from different CCMI models in comparison with ozone observations from the SBUV satellite instrument. Note, the contours used are every 5% on the negative side and every 1% on the positive side. The models show different degrees of agreement with the observations, however most of them are still suffering from a long-standing issue of a too late vortex breakup in spring. [Figure courtesy Luke Oman, NASA]*

latter showed more realistic trends. The CCMI models also captured ENSO-induced stratospheric ozone changes and a QBO-induced time lag of one year between the late-winter middle stratospheric N_2O and wintertime lower-stratospheric N_2O concentrations. These results indicate that CCMI models are able to simulate the overall temporal variability and long-term trends of stratospheric chemical species.

David Plummer presented a more detailed comparison between REF-C1 and REF-C1SD simulations. Both climatological and interannual variability of total column ozone are better simulated by the REF-C1SD than the REF-C1 runs, as would be expected from simulations forced by observed natural variability rather than using free-running models. However, interestingly, the specified dynamics simulations do not narrow inter-model spread in tropical upwelling. However, analysis of the tropical to mid-latitude difference in age-of-air suggests the specified dynamics simulations significantly narrow the estimates of mixing in the lower stratosphere.

Björn-Martin Sinnhuber compared ozone concentrations in the REF-C1SD runs with ozonesonde observations at Ny-Ålesund, Spitsbergen (79°N, 12°E), and aircraft measurements from the Polar Stratosphere in a Changing Climate (POLSTRACC) campaign. His study indicates that CCMI models generally underestimate wintertime Arctic ozone depletion, a deficiency partly attributable to Cl_y transport in the models. **Martin Dameris** examined short- and long-term fluctuations of stratospheric ozone and water vapour in EMAC simulations. The timing of full ozone recovery in the different simulations was shown to vary from region to region, and to be strongly influenced by the respective emissions scenario chosen. Unlike stratospheric ozone, lower stratospheric water vapour shows no significant trend over the past 50 years. It is, however, projected to increase in a warming climate.

The last speaker, **Lucien Froidevaux**, compared REF-C1 and REF-C1SD runs from WACCM to upper stratospheric observations from the Aura-MLS limb satellite instrument. Consistent with other presentations, the REF-C1SD run shows more realistic interannual, semi-annual, and annual variability of upper-stratospheric ozone than the REF-C1 run. The specified dynamics also results in more realistic temporal variability of chemical species (*e.g.*, HNO_3, N_2O, H_2O, and HCl) and temperature in the polar lower stratosphere. However, both REF-C1 and REF-C1SD runs failed to reproduce the wintertime enhancement of upper-stratospheric nitric acid. Water vapour variability is also underestimated in both simulations, suggesting that there still is room to improve the model.

Observations for Model Evaluation

The CCMI Steering Committee invited five researchers to give presentations on various observational datasets given the importance of observations for CCM trace gas and aerosol evaluations and constraining model processes. **Jonathon Wright** presented the origins and impacts of differences in reanalysis diabatic heating rates in the tropical tropopause layer. He showed that the sources of these differences include both variables that are well constrained by data assimilation (*e.g.*, temperature, tropospheric water vapour) and variables that are not (*e.g.*, clouds, stratospheric water vapour).

Valérie Thouret presented the 20-year record of IAGOS ozone data collected aboard commercial aircraft. This unique record of ozone in the troposphere and upper troposphere/lower stratosphere provides long-term constraints on stratosphere-troposphere exchange (STE) and tropospheric chemical and dynamical processes. IAGOS also offers simultaneous measurements of CO, NO_x, NO_y, cloud droplets, aerosols, and greenhouse gases. **Martin Schultz** discussed the potential of the tropospheric ozone assessment report (TOAR) database, the "world's largest collection of surface ozone data", and introduced useful web tools that could be beneficial for supporting CCMI efforts.

Roisin Commane discussed the value of various aircraft datasets for evaluating CCMs. Her presentation focused on the HIPPO and ATom campaigns, which sampled numerous tropospheric trace gases, including greenhouse gases, and aerosols over the Atlantic and Pacific Oceans during several seasonal deployments. Finally, **Colette Heald** discussed observationally-driven constraints on model studies of tropospheric aerosol, including black carbon (BC), secondary organic aerosol, and brown carbon.

Stratosphere-Troposphere Coupling

The session on stratosphere-troposphere coupling featured a number of presentations investigating the dynamical response to changes in radiative forcing. An invited presentation by **David Ferreira** put forward the idea that the response of sea surface temperatures and sea-ice around Antarctica to ozone depletion is governed by an initial transient response due to increased equatorward mixing of cold water with an associated increase in sea-ice extent. This is followed by a longer-term response related to increased mixing of warmer sub-surface ocean water that results in decreases in sea-ice. An analysis of CMIP5 simulations suggests a large spread across models in the timing of the transition to the longer-term response.

Sabine Haase presented a comparison of the Southern Annular Mode (SAM) response to interactive or specified ozone in WACCM. While both interactive and specified ozone simulations overestimate the stratospheric dynamical response to ozone depletion, the response is considerably better in a more recent version of the model with a modified gravity wave drag parameterization that has resulted in a reduced climatological cold bias in austral winter/spring polar temperatures. **Seok-Woo Son** looked at the influence of long-lived greenhouse gas and aerosol forcing on the Southern Hemisphere. Earlier studies conducted on a small number of models had shown that aerosol-only forcing, though it is largely limited to the Northern Hemisphere, can have significant effects on the SAM.

The larger set of models analysed here showed only a weak and inconsistent effect of aerosol forcing on SAM trends.

Invited presentations by **Susann Tegtmeier** and **Ryan Hossaini** focused on very short-lived substances (VSLS). Susann detailed recent work to develop an improved mechanistic understanding of fluxes of sulfur compounds that contribute to stratospheric sulfur, underlining a significant discrepancy between top-down and bottom-up estimates of the total flux of sulfur to the stratosphere. The talk by Ryan discussed possible future impacts of dichloromethane on Antarctic ozone recovery. While only a small fraction of stratospheric chlorine is currently derived from dichloromethane, if tropospheric trends seen over the last decade continue the contribution could reach 20 to 30% by 2050 and result in a decades-long delay in recovery of Antarctic spring-time ozone.

A presentation by **Amanda Maycock** looked at the effect of the solar cycle on ozone in available observations, CCMI simulations, as well as the historical ozone datasets for CMIP5 and CMIP6. There continues to be significant uncertainty in the observational constraints on the response of ozone and significant variability across models. The CMIP6 ozone database shows a considerably weaker response of ozone to the solar cycle than the CMIP5 database, particularly around the stratopause. A pair of presentations also looked at large-scale transport in the CCMI models, with a particular focus on simulations using specified dynamics.

Andreas Chrysanthou showed that while specified dynamics simulations from different models reproduce the interannual variability in tropical upwelling, they do not reduce the spread across models in terms of the magnitude of tropical upwelling. At longer timescales, similar to the earlier CCMVal models, all CCMI free-running simulations show an acceleration of the Brewer-Dobson circulation to 2100 with a continued large spread across models in the projected magnitude of the acceleration. **Clara Orbe** presented an analysis of tropospheric transport using a variety of idealised tracers specified for the CCMI simulations. Her analysis showed that the transport of Northern Hemisphere mid-latitude surface air to the Arctic and inter-hemispheric transport to the Southern Hemisphere is significantly influenced by the strength of deep convection in the model, particularly at lower latitudes and over the oceans. Somewhat analogous to the findings for the stratosphere, the specified dynamics simulations show as large, or larger, differences across models in large-scale transport timescales as the free-running simulations.

Troposphere Chemistry and Dynamics

The session began with an invited talk by **Kengo Sudo,** who presented a study using the CHASER-MIROC model on the causes, including climate change and changes in emissions, of interannual variability and long-term trends in global tropospheric chemistry (*e.g.*, ozone, methane) and aerosols over the last few decades.

The subject of **Fiona Tummon**'s presentation was attributing changes (*e.g.*, air pollution emissions, STE) in European free tropospheric ozone over the last several decades. She concluded that the observed increase in the 1990s was not likely associated with increasing STE, but rather from changes in *in situ* ozone production rates and possibly in tropospheric circulation patterns. She explained that the lack of trend since 2000 was due to a combination of factors, including some increase in STE, but larger changes in *in situ* production because of changing chemistry regimes. Increases in the contribution of Asian and tropical sources may also have played a role.

A presentation by **Alok Pandey** focused on a comparison of satellite-derived and UKCA model-simulated air pollution over India. He used numerous satellite datasets, including for NO_2, CO, fire-counts, formaldehyde, aerosol optical depth, SO_2, and total column ozone, to give a first assessment of the fidelity of the model over India.

The next speaker, **Miyazaki Kazuyuki**, presented the potential for a spatio-temporal evaluation of ACCMIP and CCMI model performance using a multi-constituent chemical reanalysis. This study highlighted that using such a combined measurement-model dataset could significantly reduce uncertainties introduced in model validation exercises using only *in situ* observations at certain locations.

To round off the session, **Julie Nicely** gave a presentation on using a neural network to diagnose the causes of very large differences in model

***Figure 21**: Participants of the CCMI workshop held at MétéoFrance, Toulouse, France, from 13-15 June 2017.*

simulations of tropospheric OH. She highlighted the causes (e.g., J(O^{1}D), water vapour, CO) of differences in models participating in the CCMI simulations.

Final session – Impacts of air pollution

In the final session, **Kentaroh Suzuki** (invited) discussed the significance of cloud and precipitation processes for aerosol-climate interactions. He found that the climate response to BC is much smaller than expected, with absorbing and scattering aerosols having distinctly different impacts on climate and the hydrological cycle. He also showed that indirect effects are still the largest source of uncertainty.

The last two talks, both invited, focused on air quality. **Loretta Mickley**'s highlighted the sometimes-overlooked health effects of greenhouse gas emissions via the impact of climate change on air quality. She discussed the benefits of both statistical (e.g., low computational expense) and CCMs (e.g., able to investigate physical processes), including how statistical models can provide a means to test the sensitivity of air quality to changing meteorology in CCMs. **Jordan Schnell** set out to answer questions about global air pollution episodes, including "What are they?", "What causes them?", and "How will they change?". He identified the primary drivers of these episodes. From the CCMI perspective, current CCMs would need to also simulate the feedbacks of temperature on both anthropogenic and biogenic emissions, soil moisture/ drought, and possible hourly variations in emissions to properly predict future pollution episodes.

Updates on Directions and Plans of CCMI

CCMI has been running for five years now, so the CCMI SSC decided to use some time during the workshop to reflect and discuss possible re-direction of the activity, soliciting the input of the entire CCMI community. Extended discussions were held on the questions of 'What went well?' and 'What did not go so well?' within Phase-1 of the activity. An overarching and positive message was that CCMI is perceived as having very successfully built up a strong sense of community among chemistry-climate modellers and in providing an appreciated platform for discussions on chemistry-climate related science issues. The strong links to the WMO ozone assessment and CMIP efforts were also highlighted. On the other hand, still more effort is needed to involve observationalists in multi-model evaluation. Also, more scientific progress is needed to find relevant evaluation approaches and diagnostics for the models in the troposphere. Other main issues concern the storage and accessibility of model data, as well as the choice of model output requested. (Note for the time being we encourage you to contact the modellers directly for help if you cannot find the data you need on the BADC website). This and further input received will be used to define future plans for CCMI, which will be reviewed by the IGAC Scientific Steering Committee in late 2017 and thereafter communicated to the CCMI community. If you were not at the workshop and would like to help shape the future of CCMI, please do not hesitate to send your input to the co-leads **Bryan Duncan** (Bryan.N.Duncan@nasa.gov) and **Michaela Hegglin** (m.i.hegglin@reading.ac.uk).

In the near-term, of particular importance to the CCMI community are the deadlines imposed by the WMO/UNEP Ozone Assessment schedule. Authors of assessment-related studies should make the lead-authors of the various chapters aware of their work by 15 September 2017. More importantly, studies need to be accepted by 15 May 2018 to be citable in the assessment. Also, the CCMI community will become heavily involved in the production and evaluation of the CCMI Phase-2 AerChemMIP simulations in strong collaboration with the AeroCom community. This will happen between early 2018 and late 2020. How to get involved in this activity will be announced later in 2017 through the quarterly CCMI e-News. If you are not on the CCMI emailing list, but would like to sign up, send a message to m.i.hegglin@reading.ac.uk.

Finally, the next CCMI workshop will likely take place in 2019, with exact dates and location to be determined. (Please contact the CCMI co-chairs if you are keen to host this meeting). However, in the meantime, we encourage a strong CCMI community participation in the 2018 joint 14th iCACGP Quadrennial Symposium and 15th IGAC Science Conference to be held from 25-29 September 2018 in Takamatsu Kagawa, Japan, as well as in the subsequent 6th SPARC General Assembly to be held from 1-5 October 2018 in Kyoto, Japan.

References

Cionni, I., *et al.*, 2011: Ozone database in support of CMIP5 simulations: results and corresponding radiative forcing, *Atmos. Chem. Phys.*, **11**, 11267-11292, **https://doi.org/10.5194/acp-11-11267-2011**.

Eyring, V., *et al*, 2013: Overview of IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) Community Simulations in Support of Upcoming Ozone and Climate Assessments, *SPARC Newsletter*, **40**, 48–66.

Morgenstern, O., 2017: Review of the global models used within phase 1 of the Chemistry–Climate Model Initiative (CCMI), *Geosci. Model Dev.*, **10**, 639-671, **https://doi.org/10.5194/gmd-10-639-2017, 2017**.

The First TUNER Meeting

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DATE:
15 June 2017

ORGANISERS:
Thomas von Clarmann, Doug Degenstein

HOST INSTITUTION:
University of Saskatchewan, Canada

NUMBER OF PARTICIPANTS: 20

SPONSORS:

BACKGROUND:
TUNER (Towards UNified Error Reporting) is an emerging SPARC activity aiming to provide a complete and consistent data characteriSation in terms of uncertainty, resolution, and content of a priori information, for the largest possible number of space-borne temperature and composition sounders.

ACTIVITY WEBSITE:
www.sparc-climate.org/activities/emerging-activities

The first meeting of the emerging SPARC activity "Toward Unified Error Reporting (TUNER)" was held at the University of Saskatchewan, Saskatoon, Canada, on 15 June 2017. The aim of this project is to harmonize the reporting of uncertainties of satellite data of atmospheric temperature and composition.

In order to get an inventory of the retrieval methods and error estimation schemes used in the satellite community, a questionnaire was distributed to the instrument/data processing teams. The responses were presented by **Thomas von Clarmann** and discussed in Saskatoon. Responses were obtained for 12 limb and one nadir mission. Limb missions include limb emission, limb scattering, and occultation. Measurements in the following frequency ranges were represented: microwave, far-infrared (IR), IR, near-IR, visible, and ultraviolet. All retrievals are based on a matrix formalism with or without regularisation, the latter being either optimal estimation or Tikhonov-type. Some groups provide their data on the native retrieval grid, while others interpolate their data to a regular grid after the retrieval. In the latter case, care has to be taken to also transform the diagnostic data onto the new grid. Good agreement was found with respect to the schemes for estimating how noise is propagated into the results, but the estimation of parameter errors needs much more discussion. Since such parameter errors depend largely on instrument specifics and the retrieval strategy chosen, harmonization of related error reporting is not expected to be a trivial task. All participating groups seem to be well aware of possible forward model errors which might affect their results but quantification of these is often difficult. Some groups prefer to provide total error estimates to the data users while others find it more appropriate to provide information on the error components and to leave their combination to the data users. Averaging kernels are provided by all groups who perform constrained retrievals. No agreement has thus far been reached about the altitude resolution of non-constrained retrievals. Validation papers are available for most of the participating instruments. Within TUNER no validation studies will be made, but it will heavily draw upon existing validation studies; these are considered particularly useful to judge which error estimation schemes are adequate. In order not to duplicate work ongoing in other projects, it was decided not to assess instrument drifts within TUNER.

The next point on the agenda was deductive error analysis, which is understood to be the propagation of ingoing uncertainties through the retrieval system. Several talks were given on

Figure 22*: Participants of the first TUNER workshop held at the University of Saskatchewan, Saskatoon, Canada, on 15 June 2017.*

this topic. **Natalya Kramarova** and **Patrick Sheese** presented results of error estimation work done for OMPS and ACE-FTS, respectively. Both studies included detailed analyses of the leading error sources. **Thomas von Clarmann** discussed the problem that covariances between the atmospheric state and averaging kernels can cause the application of mean averaging kernels to a mean profile to be inaccurate. Instead, he suggested using a mean covariance term for correction. **Stefan Bender** reviewed machine learning methods and raised the question of whether these might be useful within TUNER, as their mathematical structure is similar to that of retrieval and error estimation.

Under the header of inductive error analysis, which is understood to be error analysis based on the observations, and which is thus closely related to validation, two presentations were given. The first, by Arne Babenhauserheide, Quentin Errera, and **Thomas von Clarmann** (presented by the latter) tackled the problem of natural variability. This, along with less than perfect co-locations of measurements seems often to be used as a "universal excuse" whenever discrepancies between two datasets are encountered in validation studies. Highly-resolved temperature and mixing ratio fields calculated with the BASCOE model were used to statistically quantify the effect of spatial and temporal mismatch between observations. In the following presentation Thomas showed, by comparing three or more datasets, that their precision estimates can be assessed such that it becomes clear which instrument group over- or under-estimates their random uncertainties. It was agreed that this method showed promise and should be further investigated within TUNER.

A problem has been identified with respect to how user-driven TUNER should be. On the one hand, the data users should be provided with the error estimates and other diagnostic data they need. However, on the other hand, data users often do not know how relevant certain diagnostics (e.g. averaging kernels or error covariances) are and would thus never request them. The following solution has been identified: Instead of asking the data users which diagnostics they would like, they will be asked for which applications they require satellite data. The data providers will then decide which diagnostics will be necessary.

Finally, TUNER has been selected as an International Team by the International Space Science Institute in Bern, Switzerland, where two project meetings will be held, and it was decided to propose a special issue on TUNER to the journal Atmospheric Measurement Techniques.

SPARC meetings

2 – 5 September 2017
Training School on Stratosphere-Troposphere Interactions, Cape Town, South Africa

6 – 8 September 2017
Workshop on the Measurement of Stratospheric Aerosol, Boulder, Colorado, USA

9 – 14 October 2017
FISAPS, QBOi, and SATIO-TCS joint workshop, Kyoto, Japan

16 – 20 October 2017
25th SPARC SSG meeting, ECR symposium, and regional workshop, Seoul, Republic of Korea

23 – 25 October 2017
S-RIP 2017 Workshop, Reading, UK

25 – 27 October 2017
SPARC Data Assimilation Workshop, Reading, UK

6 – 9 November 2017
SOLARIS-HEPPA Working Group Meeting, Paris, France

5 - 8 February 2018
The UTLS: Current status and emerging challenges, Mainz, Germany

SPARC-related meetings

21 – 25 August 2017
10th International Carbon Dioxide Conference, Interlaken, Switzerland

27 August – 1 September 2017
IAPSO-IAMAS-IAGA Conference: Good Hope for Earth Sciences, Cape Town, South Africa

18 – 22 September 2017
COSPAR Symposium 2017, Jeju-do, Republic of Korea

13 – 17 November 2017
5th International Conference on Reanalysis (ICR5), Rome, Italy

11 – 15 December 2017
AGU Fall Meeting, New Orleans, USA

5 – 9 February 2018
AMOS-ICSHMO 2018, Sydney, Australia

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