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Sunrise at Scott Base, McMurdo Sound, Antarctica in late September 2006. At the end of the polar night, the sun returns to Antarctica. Because it is still very low, red and orange colours dominate. With the end of the polar night, the sun brings the energy needed in the chemical processes that cause the large Ozone depletion leading to the known phenomenon of the 'Ozone hole' over Antarctica. The protection of the ozone layer was agreed through the Vienna Convention and the Montreal Protocol signed in 1985 and 1987 respectively. Observations of trends in Ozone have since been a scientific focus, e.g. of the SPARC LOTUS activity (see report on page 8).

Photo credit: Katja Riedel Photography

Contents

WCRP World Climate Research Programme | WMO | UNESCO | IOC | ICSU International Council for Science

39th session of the WCRP Joint Scientific Committee

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The thirty-ninth session of the Joint Scientific Committee (JSC-39) of the World Climate Research Programme (WCRP) was held at the Nanjing University of Information Science & Technology (NUIST) in Nanjing, China, from 16 April to 20 April 2018.

The session started with a warm welcome by Vice President and Vice Chancellor of NUIST, **Guan Zhaoyong**, who described the role of the University and its significant history of meteorological studies since 1960. He emphasised the partnership with international universities and institutions through the WMO Regional Training Centre Nanjing. JSC chairperson **Guy Brasseur** also welcomed the participants and sincerely thanked the Chinese hosts, mentioning China's high interest and active involvement in climate change research towards a leadership role in future climate change research. For WMO, Deputy Secretary-General **Elena Manaenkova** thanked NUIST for hosting the meeting. She emphasised WCRP's role and underscored, as an example, that the four highest risks mentioned in the 2018 Global Risk Report are related to climate changes and climate extremes. Hence, WMO sees a crucial need to enhance the understanding of the Earth system – a core task of WCRP. **Salvatore Arico** of the Intergovernmental Oceanographic Commission (IOC; remotely connected) confirmed the important task of WCRP in providing information and observation and advocated an enhanced emphasis for ocean science within the WCRP.

Strategic plan and implementation plan

It is critically important for WCRP to thoroughly review its structure (including SPARC and the other core projects) in order to support scientists from around the world who effectivelky contribute to research underlying WCRP. There is also the need to make its aims and rationale attractive for its key sponsors as well as to outside parties, e.g., funding agencies.

During the session, all groups and projects had the opportunity to report their activities (see below). The presentations covered achievements of the past year and plans for the future. In addition, they gave all branches of WCRP the possibility to state their needs for the coming decade and to provide input to the strategic plan. The focus of the session was put on furthering the new WCRP scientific strategic plan 2019-2029. Discussions on the content of an implementation plan also took place, both in the plenary and in breakout groups.

Elena Manaenkova provided the context by sketching the current WMO strategy 2030, consisting of these overarching priorities:

1. Furthering preparedness for and reducing losses of life and property from hydro-meteorological extremes;

2. Supporting climate-smart decision making to build resilience and adaptation to climate risk, and

3. Enhancing socioeconomic value of weather, climate hydrological and related environmental services.

Long-term goals were defined to underpin these priorities. One is termed "Advance targeted research: Leveraging leadership in science to improve understanding of the Earth system for enhanced services" and is tackled by WCRP and WWRP. The entire WMO structure was redefined for the next decades, with the phrase "What do we want to achieve in the next 40 years?" as a fundamental guideline.

Guy Brasseur emphasized the importance of the strategic plan to comprise the core tasks of WCRP, which scientists from around the world can identify with and support actively. Fundamental climate science should remain the focus. He asked for an open discussion to use the opportunity to rejuvenate WCRP, suggested openness to fundamental ideas, and underscored the need for strengthening partnerships. In the plenary discussion, it was stresses that the strategic plan should express the value that WCRP provides as the international coordinator of climate science. Furthermore, the intended readership has to be kept in mind as WCRP's future will fundamentally depend on the support of climate scientists, of research funding agencies, as well as of relevant political and scientific organizations.

In the breakout sessions it was repeatedly emphasised that WCRP relies on the wide community of scientists participating in its numerous activities and projects. These groupings must be enabled and strengthened by the new strategy. Likewise, the formulation of a strategic plan is seen as a chance to give WCRP a sharpened profile that facilitates communication with sponsors and enhances the programme's visibility to society. Structural changes that might come with the implementation should be used to strengthen bonds with regional activities (for example, it was suggested to use the international program offices as connecting points to regional agencies and communities).

The JSC-39 participants agreed on the necessity to reconsider activities and the formulation of over-arching interests. The breakout groups produced various ideas for the future shape of WCRP. A common focus was to retain the core strengths of the programme, which consists of communities around the core projects, and - at the same time - encouraging these communities to better interact on cross-cutting issues. The S2S initiative is regarded as a good example with clearly defined goals which necessitate good links to all parts of WCRP as well as of WWRP.

An overview of the strategic plan is scheduled as an invited presentation by Guy Brasseur during the SPARC General Assembly 2018. After an open consultation process about the strategic plan (**www.wcrp-climate.org/wcrp-sp-pc**), an implementation plan will be produced based on the JSC discussions and the outcome of the consultation.

Working group reports

For the *Working Group on Numerical Experimentation* (WGNE), **Keith Williams** (remotely connected) emphasised WGNE's broad reporting role for WCRP and beyond, and considered the group as pioneer of seamless studies, with the MJO task force working across all time scales as a pertinent example. The WGNE drag project addressing the parametrized components of surface stress and its partitioning between schemes (e.g. planetary boundary layer, sub-grid orography) is about to evolve into a new project focussing on momentum. Furthermore, a joint project with the WWRP working group on *Predictability, Dynamics, Ensemble Forecasting* (PDEF) is being discussed. Regarding the WCRP review, WGNE agrees that model development groups should go across timescales. A single working group cannot cope with the development of the different Earth systems across all time scales, while adding another panel to oversee the model work only increases bureaucracy. Nevertheless, WGNE proposes to act as a focal point for model development activities and to retain primary expertise for atmospheric model development while cooperating closely with groups for other geophysical compartments.

The *Coupled Model Intercomparison Project Phase 6* (CMIP6) was introduced by **Greg Flato** as he presented the *Working Group on Coupled Modelling* (WGCM). The project output is targeted to provide input to the next IPCC assessment. Currently, 33 modelling groups are participating and two new MIPs have been defined. Through CMIP6, the community behind WGCM provides WCRP with essential and highly visible products, a most valuable heritage. The report concluded that the coordination of climate modelling through comparison projects as well as of the underpinning model development should remain a central task of WCRP.

Bill Merryfield reported for the *Working Group on Sub-seasonal to Interdecadal Prediction* (WGSIP), which comprises 13 members representing various projects, including S2S and GEWEX/GLASS. A task group is intended to narrow the gap between research and operations, in line with the motto "enabling services rather than providing them". For the future, the necessity for enhanced cooperation with WCRP's core projects and Grand Challenges was stressed.

For the *Sub-seasonal to Seasonal Prediction Project* (S2S), **Andrew Robertson** reported that the S2S-database is being used increasingly, but was facing funding problems. There is a significant interest from developing countries to obtain S2S forecasts. A proposal for a 5-year extension of S2S (2018-2023) was submitted to WMO. The second phase includes topics as database enhancement, new sub-projects on MJO prediction and teleconnections, the relative roles of ocean and sea ice, land surface, stratosphere as well as atmospheric composition and ensemble generation. Additional aims are enhancement of operational infrastructures, development of user applications, and a real-time forecast pilot experiment.

From the working group reports suggestions were collected for possible inclusion in both, the strategic plan and the implementation plan. They included a co-design with stakeholders, model evaluation and verification, as well as the need for data bases, infrastructure, protocols, and open access. As open points remained topics like how far into 'operational' model development WCRP should go, whether there is a critical mass of resources and engagement, and whether WCRP should aim for model development across all time scales, following the value chain closely, and across disciplines.

Reports from CORDEX and Core Projects

William Gutowski presented the *Coordinated Regional Downscaling Experiment* (CORDEX), which focusses on the regional aspects of WCRP science, and provides a direct link between climate and its impact on communities. He identified high quality, fine-scale, and multivariate observations as a key need for the high resolution models. Peculiar to CORDEX is the tendency that semi-independent core groups form in different regions impeding at times overall coordination. The regions differ in their access to funds which challenges a balanced development of the core groups. In conclusion, it was stressed that science should stay curiosity-driven, and while stakeholder needs have to be taken into account they should not formulate research priorities.

For SPARC, **Neil Harris** presented some of its activities (e.g., LOTUS and CCl_4) with clear timelines related to issues of the Montreal Protocol, and others of a more general science underpinning. He emphasised that for ozone depletion the governments would not seek more evidence for the existence of the problem, but rather need advice on possible actions. Possibly, the Paris Agreement prooves to be a turning point in the climate debate; then WCRP should react in an appropriate fashion. Following a number of recent achievements from SPARC activities, the presentation contained an outlook for SPARC's future, the mention of two SSG positions being reserved for colleagues from South America and Africa, and the intention for enhanced internal and external collaboration under a new strategic plan. The plan is to define the "boundaries" to other core projects. Furthermore, the new implementation plan has to seek financial resources commensurate to WCRP's future aims.

The *Global Energy and Water Cycle Experiment* (GEWEX), investigating the heat reservoirs and fresh water resources on the planet, was presented by **Graeme Stephens**. A new panel in *Global Atmospheric System Studies* (GASS) was formed focussing on moist atmospheric processes in the evaluation of model physics. Large cooperation potentials with SPARC were identified, considering the atmospheric part, especially with respect to *Process Evaluation Studies* (PROES), as well as troposphere-stratosphere interactions, and deep convection.

Detlef Stammer presented recent developments within the *Climate and Ocean: Variability, Predictability, and Change* (CLIVAR) project. A science plan was recently finalised, organising the project through panels and research foci. A new panel to coordinate and facilitate activities on the role of the northern oceans in the context of the global climate system from a coupled ocean-air-ice perspective (CLIC/CLIVAR NORP) is considered to fill a gap in the science programme. CLIVAR is to organise yearly schools on CLIVAR related and societally relevant science, alternating between Qingdao (China) and Trieste (Italy), and funded through external sponsors. It was discussed how various WCRP projects on decadal variability should be handled, and plans were mentioned to merge the CLIVAR groups with other projects with similar interests.

News from the *Climate and Cryosphere* project (CliC) were presented by **James Renwick**. A highlight consisted of the "Arctic Sea Ice Prediction" stake holders workshop, held in Tromsø in January 2018. The discussion stressed that the treatment of commercial stakeholders necessitates special care, and CliC does yet not have a general strategy in this regard. CliC witnesses that numerous complementary research activities are undertaken in other organisations, which provides the challenge to seek cooperation with a wider community while concentrating up-to-date climate and cryosphere research. With regard to the strategic plan CliC underscored the urgent need for basic observations and their integration into modelling studies. Finally, the importance of CliC research for societal linkages was underscored.

Figure 1: *Participants of the JSC-39 session.*

Reports from partner projects

Several partner projects to WCRP provided updated overviews. The *Global Climate Observing System* (GCOS) recently introduced a new strategy. **Rodney Martinez** emphasised parallels to the development of the strategic plan for WCRP, e.g., the envisaged enhanced monitoring of global circulation circuits, motivated by the Paris Agreement. The need for good communication between GCOS and WCRP was underscored, as the data records collected through GCOS are needed as input for WCRP projects. Likewise, observations made during short-term WCRP projects should be fed into the GCOS database. Sharing panels is one useful possibility of interacting with the WCRP core projects. It was also noted that adaptation to climate change is an important issue which necessitates detailed information. Down-scaling of global findings continues to be a science topic with high relevance for governmental needs.

Øystein Hov used the opportunity to present ideas on science for services: a curiosity-driven circuit of discovery, translation, and application. He provided examples for potential partnerships following such a scheme – one of them being to strengthen existing links between SPARC, the *International Global Atmospheric Chemistry* project (IGAC), and the *Commission of Atmospheric Sciences* (CAS) to provide a common focus for research related with atmospheric composition.

The search for collaborative opportunities between projects was repeated in **Greg Carmichael**'s presentation for the *Global Atmospheric Watch* Programme (GAW). This WMO programme builds on cooperation involving contributions from 100 countries. As there are common interests with neighbouring programmes, GAW sees the potential for strong collaboration in a number of research topics, among them greenhouse gas fluxes, SLCPs, as well as upgrading observing systems and modelling capabilities.

For the *World Weather Research Programme* (WWRP), **Michael Morgan** identified four action areas: high impact weather, water, urbanisation, and new technologies. There is a clear need for the co-design of science activities to make advances both in science and its service for society. Furthermore, joint activities between WCRP and WWRP could help to use available resources more efficiently. Proper coordination and co-design avoided unnecessary duplication of effort and brought to bear the diverse talents of the respective communities to tackle some of humanity's most vexing environmental challenges.

Marie-France Loutre introduced the *Past Global Changes* project (PAGES), a core project of Future Earth and a scientific partner of WCRP. A link between WCRP and PAGES has been established through Gabi Hegerl (WCRP grand challenge on climate extremes) and Hugues Goosse (PAGES activity on Extreme events and risk assessment).

Grand Challenges Reports

As topical foci, WCRP supports seven Grand Challenges (GCs), each addressing for a limited period a problem area high concern within climate change research. All Grand Challenges reported increased collaboration among each other, as well as with the core projects, the working groups and external partners. Generally, concern was expressed regarding the tightening of budget limits in recent years.

Detlef Stammer introduced the GC on *Regional Sea-Level Change and Coastal Impacts*. Its key event was the International Sea Level Conference in July 2017 in New York City, attended by more than 300 participants from over 40 countries. Highlights and an Official Statement are contained in the still living website **http://sealevel2017.org**.

The GC on *Clouds, Circulation and Climate Sensitivity* concerns questions about variations in storm tracks, the position and strength of tropical rain belts, the importance of convective aggregation for climate, and the contribution of convection to cloud feedbacks. **Bjorn Stevens** (remotely connected) summarized model inter-comparison projects and introduced a coordinated field study, the EUREC4A campaign, scheduled for 2020 around Barbados. EUREC4A aims to test mechanisms that control the low-cloud feedback in climate models using several research aircraft that will be coordinated with satellites, ground stations, and ships. The GC on *Carbon feedbacks in the climate system*, launched in 2016, addresses the durability and persistence of land and ocean carbon sinks.

Pierre Friedlingstein (remotely connected) introduced inter alia a plan for a carbon predictions meeting in 2019 to discuss new analyses for the UNFCCC global stocktakes. An EU Horizon2020 proposal was submitted for the *Climate-Carbon Interactions in the Coming Century* (CCiCC), to narrow down knowledge gaps in climate science in support of IPCC reports. Concerning the WCRP strategic plan, the GC expressed the need of a stronger connection between science and policy.

Jan Polcher reviewed the GC on *Water for the Food Baskets of the World* and presented the intention of dividing the GC in two complementary research activities; one focussing on observation based studies to improve understanding of surface-atmosphere-interaction and the second aiming at enhancing predictive capabilities while climate changes and increasing human intervention increases. The refined science questions for this GC are well linked to the GEWEX science questions, while being of wider scope concerning water usage. The GC should make use of *Regional Hydroclimate Projects* (RHPs) of GEWEX and CORDEX regional activities, and seek collaboration with the WMO *Commission for Hydrology* (CHy), the UNESCO *International Hydrological Programme* (IHP) as well as the *Integrated Land Ecosystem-Atmosphere Processes Study* (iLEAPS) of the Future Earth.

For the GC on *Weather and Climate Extremes*, **Xuebin Zhang** reported coordination efforts to enhance global extreme datasets (e.g. HadEx3, INTENSE) and to model specific physical processes (e.g. high-resolution convection permitting models). He highlighted so-called Compound Events as important for the GC implementation (cf. a recent Nature Climate Change perspective article; **www.nature.com/articles/s41558-018-0156-3**). With its wide range of issues and the diversity of stakeholders for extremes, the GC regards maintaining its focus as a challenge, as it intends to remain open to research and to services communities. In light of the decision of WMO to close the joint CCl-WCRP-JCOMM *Expert Team on Climate Change Detection and Indices* (ETCCDI), the GC requested that WCRP would identify a home for these tasks with the GC-Extremes as a standing committee.

For the GC on *Melting Ice and Global Consequences*, **Greg Flato** identified numerous topics in common with the CliC project. A focus were activities targeted at the cryosphere in climate models such as Sea-Ice Model Intercomparison, Ice Sheet Model Intercomparison and the ESMSnowMIP. For the future, overlaps between CliC and the GC should be clarified. The GC received an invitation to participate in model intercomparison initiative, developed by a large European consortium.

Masahide Kimoto introduced the GC on *Near-Term Climate Prediction*, which transposed its white paper to a journal article (to be submitted to Nature Climate Change). The GC now has 19 international partners and members from all WCRP core projects. The agreed objectives include promoting and providing new knowledge about climate mechanisms and climate forecasting systems, exploring operational decadal predictions in close coordination with WMO as well as experimental decadal outlooks. To this end, this GC plans to initiate real-time "Global Annual to Decadal Climate Updates" each year, for which specific diagnostics are being developed.

Advisory Council reports

Jean-Noël Thépaut presented the work of the *WCRP Data Advisory Council* (WDAC). Major efforts are led by task teams termed obs4MIPs (to prepare observations for model intercomparison), TIRA (reanalyses inter-comparison), and SurFlux (provide surface fluxes WCRP-wide). It was stressed that observations stand at the heart of model development and process understanding, in addition to data assimilation, model verification and model initialization. It was proposed to specifically address the topic of "big data science" within WCRP, and to put an emphasis on fluxes. Likewise, attracting funding for data assimilation development was regarded as important as for model development. Finally, the need for a cross-cutting "observations/analysis" forum was stressed.

The *WCRP Modelling Advisory Council* (WMAC), presented by **Gerald Meehl** (remotely connected), is considered very active, coordinating 47 individual modelling projects (67, when counting CMIP). In 2017, WMAC initiated a WCRP/WWRP International Prize for Model Development. WMAC reported slow progress in reducing systematic model errors, called for more coordinated activities, and brought up the issue of exascale computing, which should be addressed across WWRP, GAW, and WCRP. The sheer number of modelling activities scattered across WCRP, necessitates a mechanism to facilitate communication and efficient coordination. Therefore, the current WCRP web site containing a list of active modelling projects (with short descriptions of status and chair/leader contact information) should be maintained. WMAC proposed "model development" as a task of central interest for WMO, and consequently the formation of a "working group on Model Development" involving the entire WMO research programme and also other programmes dealing with modelling aspects (e.g. AIMES of Future Earth). Finally, it was suggested that each modelling working group within WCRP has a designated model development activity that could be coordinated by the Model Development Working Group.

Early careers engagement

JSC-39 concluded with a presentation by **Victor Dike**, a representative of the YESS, the community of *Young Earth System Scientists*. He gave a short introduction of the latest development of the network, as well as the young scientists' view on the future climate science for input to the new WCRP Scientific Strategy. Dike re-emphasized the need and benefit for WCRP and for the future of climate community to actively entrain young scientists in their various activities. He also stressed that early career scientists should be encouraged of getting pro-actively involved in this process, individually and through ECR networks.

NUIST-WCRP workshop

Thursday was devoted to a scientific workshop entitled "Future Directions for Fundamental Research on the Climate System". The program was interleafed with talks on the state-of-the-art climate science in the remit of WCRP activities, presented by the scientific leaders of WCRP groups and by leading Chinese researchers. The audience was vividly engaged, asked questions, and made good use of the special opportunity for discussions with experts from all over China and from around the planet (as represented by WCRP members).

Personal thoughts related to WCRP's new Strategic Plan

Neil Harris and Judith Perlwitz (**SPARC co-chairs**)

WCRP is currently developing its Strategic Plan 2019-2029. This new plan and the related implementation plan have to take into account that climate scientists are now operating in a different political environment. Since the signing of the Paris Agreement, the role of climate scientists is to help governments meet their targets on climate change. It is much more than presenting and assessing evidence as to whether climate change is occurring. There are strong parallels to the Montreal Protocol process since 1987. Over the years, SPARC has organised numerous reports answering specific questions in advance of the UNEP-WMO Ozone Assessments, most recently the LOTUS and CTC reports. The role of similarly focussed reports organised in support of the IPCC process should be growing.

A major point of discussion at the recent WCRP-JSC meeting was how to maintain a balance between fundamental research (processes, measurements, model development, etc.) and more applied aspects (regional, economic, social, etc.). Practical aspects of accomplishing such a balance will be developed in the Implementation Plan. From a SPARC perspective it is important to have clear homes for the various facets of atmospheric dynamics and for coordinating international research on atmospheric composition.

Understanding climate globally and regionally requires coordinated research between scientists interested in the atmosphere, ice, land and ocean. However, for an increasing number of particular research topics, joint work involving multiple communities from inside and outside WCRP is required. The challenge is to assure that WCRP provides optimal coordination of these areas of common interest. The Subseasonal-to-Seasonal Prediction (S2S) Project is an excellent example of current collaborative programmes. It is a project under WCRP and WWRP sponsorship, many WCRP sub-groups are contributing (e.g., the SNAP activity of SPARC), there is strong research community interest, and it is productive. SPARC has a track record of collaboration with external partners such as IGAC and GAW and should support other interdisciplinary initiatives on topics such as convection or radiative forcing.

At its 39th session, the WCRP-JSC discussed intensely the role of the scientific communities in a revised WCRP. The strength of the communities is outstanding as seen by the number of scientists attending the recent General Assemblies of the core projects (including the upcoming SPARC GA in 2018). These communities roughly correspond to the four current core projects (dealing with atmosphere, ice, land and ocean, respectively) and regional activities with some omissions in certain technical areas (model development). We are keenly aware of the contributions of so many excellent scientists to SPARC's success and think it is essential that everyone who wants to can identify with some part of the revised WCRP. We fully recognize that the nature of that home will evolve over time as new interdisciplinary challenges are being addressed.

The new WCRP Strategic Plan is currently open for discussion (**www.wcrp-climate.org/wcrp-sp-pc**). As current co-chairs of SPARC, we strongly recommend that all interested SPARC scientists read it and provide their thoughts as SPARC and WCRP's success crucially depends on broad intellectual support.

SPARC/IOC/GAW report on Long-term Ozone Trends and Uncertainties in the Stratosphere

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WMO/UNEP Ozone Assessments rely on the accurate evaluation of total column and profile ozone trends and associated uncertainties. These trends are a primary metric used to evaluate model-based simulations of ozone layer recovery and assess the success of the Montreal Protocol. The SPARC *Long-term Ozone Trends and Uncertainties in the Stratosphere* (LOTUS) activity was established in 2016 to evaluate the quality of recent ozone profile observational records, to test the sensitivity of trend results to proxy choice in statistical trend models, and to investigate approaches to better estimate uncertainties in merged ozone records and when combining trend estimates from satellite and ground-based records.

The first phase of LOTUS was primarily targeted at providing timely input to the 2018 WMO Ozone Assessment. During this phase we reevaluated the satellite and ground-based data records as well as the time series analysis methods commonly used to derive long-term trends. Using a single "LOTUS regression" model, we reassessed past and recent trends in the vertical distribution of stratospheric ozone from the updated individual data records. We then developed a new approach to combine the individual trend estimates from satellite-based records into a single best estimate of ozone profile trends including associated uncertainty estimates. Finally, we compared the satellite-based profile trends in broad latitude bands to trends from ground-based data, from the collection of CCMI-1 model simulations, and from past evaluations of satellite-based trends in peer-reviewed literature. The main results of the first phase of LOTUS are:

- The assessment of long-term observations by LOTUS confirms the significant decline of ozone concentrations in the upper stratosphere (at altitudes above the 10–5 hPa level) between January 1985 and December 1996. Strongest trends are observed near 2hPa (~42 km) with values of 5.9–6.2% per decade at mid-latitudes and 4.8% per decade in the tropics. Trends are significant at more than 5 standard deviations in this altitude range.
- Trends derived from satellite and ground-based records in the pre-1997 time period agree with climate model simulations within respective uncertainties, confirming our understanding of ozone loss processes in the upper stratosphere during that period.
- For January 2000 to December 2016 positive trends are obtained throughout the upper stratosphere for satellite and ground-based records. The combined trends from six merged satellite records are larger in the Northern Hemisphere (NH) mid-latitudes (2–3% per decade between ~5–1 hPa) than in the tropics (1–1.5% per decade between ~3–1 hPa) and Southern Hemisphere (SH) mid-latitudes (~2% per decade near 2 hPa). Statistical confidence is largest for trends in the NH mid-latitudes.
- For altitudes below the 4 hPa level, ozone trends in the post-2000 time period are not significant. Persistent negative ozone trends of 0.5–1.5% per decade detected by satellite combined records in the 50–15 hPa altitude range over the tropics suggest an impact from radiative and dynamical greenhouse gas forcing. However, these negative trends are not entirely supported by the CCMI models and some ground-based ozone records. At mid-latitudes, the trend estimates are close to zero down to 50 hPa.
- Larger differences in post-2000 trends from the various records are observed in the lowermost stratosphere (100–50 hPa) in all latitude bands. Non-significant negative trends are derived from merged satellite records over the tropics and the NH mid-latitudes. Model simulations show positive trends in the mid-latitudes in both hemispheres in this altitude range, although these are not statistically significant.
- LOTUS estimates of past and recent ozone trends are in fairly good agreement with results from previous studies (e.g., WMO, 2014; Harris *et al.*, 2015;

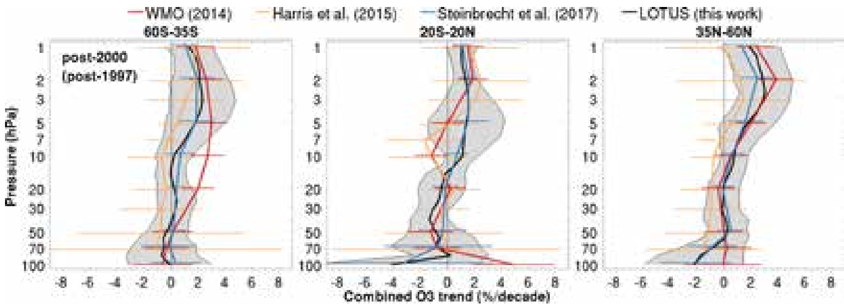

***Figure 2:** Overview of ozone profile trends from past and recent assessments: WMO (2014), Harris et al. (2015), Steinbrecht et al. (2017), and LOTUS (this work) are depicted in red, orange, blue, and black respectively. Shown are trends since the turnaround of ODSs (analysis time period differs by assessment, i.e. post-1997 and post-2000). Shaded area and error bars represent the 95% confidence interval for the combined trend. Colored profiles are slightly offset in the vertical for display purposes.*

Steinbrecht *et al.*, 2017; and references therein). For the post-2000 period, the largest differences are found throughout the middle stratosphere. These differences stem primarily from extensions of and revisions to existing data records, the addition of new data records, and in some cases the use of a different trend model.

- While trend values in recent studies are fairly similar, the uncertainties and hence significances of the combined trends in broad latitude bands differ substantially. The LOTUS approach, based on both error propagation and standard error of the mean, differs from the study by Steinbrecht *et al.* (2017) in the effective number of independent data sets and thus yields lower confidence in positive trend values throughout the upper stratosphere.

- In the lower stratosphere, ozone trends are more uncertain due to large atmospheric variability and the decreased sensitivity of satellite measurements. Additional studies are needed to assess trends from satellite and ground-based records in this particular region.

Estimates of combined satellite trends in LOTUS report are reported for two distinct time periods. The "pre-1997" is defined as the period from January 1985 to December 1996, while "post-2000" refers to the period from January 2000 to December 2016 (see result in Figure 2). Comparisons of LOTUS trends with previously published trends (WMO, 2014; Harris *et al.*, 2015; Steinbrecht *et al.*, 2017) are shown in Figure 2 as well.

The LOTUS report assessment of satellite and ground-based ozone data sets builds the foundation for reconciling the discrepancies in ozone trends estimated from the individual climate data records. Understanding the causes of these differences would create improvements not only in the internal consistency of data sets, but also in the uncertainties of overall ozone trends. Further, development of techniques to directly assess uncertainties in the merged records resulting from discrepancies that cannot be completely reconciled, such as small relative drifts and differences resulting from coordinate transformations and sampling differences, would allow for a more precise estimate of significance of the mean trend.

For the ground-based and satellite data used in the LOTUS report, information on stability and drifts of the measurement is still incomplete. The homogenization of ozonesonde records was not finished prior to their use in the LOTUS assessment, and thus the ozonesonde trends and their uncertainties (especially in the lower stratosphere) may change in the future. In addition, in order to properly combine instrument-specific trends, a common matrix of error budget information for each ozone record is needed.

Pressure (hPa)	**Ozone trend Jan 1985 – Dec 1996** (% per decade, ± 2σ)			**Ozone trend Jan 2000 – Dec 2016** (% per decade, ± 2σ)		
	60–35°S	**20°S–20°N**	**35–60°N**	**60–35°S**	**20°S–20°N**	**35–60°N**
1	-2.8 ± 3.1	-2.0 ± 3.2	-3.3 ± 3.2	1.3 ± 1.8	1.0 ± 1.2	1.9 ± 2.3
2	-6.0 ± 1.7	-4.4 ± 1.2	-5.8 ± 1.7	2.1 ± 2.1	1.3 ± 0.9	2.9 ± 2.1
5	-3.4 ± 2.4	-2.6 ± 3.0	-2.8 ± 2.7	1.8 ± 2.2	1.4 ± 2.8	1.8 ± 2.0
7	-2.2 ± 1.5	-1.1 ± 1.9	-2.5 ± 1.8	1.1 ± 1.7	1.2 ± 2.5	1.1 ± 1.4
10	-1.0 ± 1.4	-0.8 ± 1.5	-2.5 ± 1.5	0.2 ± 1.4	1.1 ± 1.2	0.8 ± 1.0
20	0.0 ± 1.9	-0.9 ± 1.7	-1.7 ± 2.5	0.2 ± 1.3	-0.5 ± 1.7	0.0 ± 1.2
50	-2.2 ± 2.7	-2.4 ± 3.3	-2.1 ± 2.3	-0.3 ± 1.6	-0.9 ± 2.1	0.2 ± 1.5
70	-1.2 ± 4.5	-1.9 ± 5.3	-4.5 ± 3.8	-0.6 ± 2.4	-0.7 ± 3.3	-0.9 ± 2.4

***Table 1:** Overview of LOTUS combined satellite trends in three latitude bands and two time periods. Central values and uncertainties representing the 95% confidence interval are given. Trend results that are statistically significant at the 2-sigma level are highlighted in grey. Trends and uncertainties presented here are interpolated onto pressure levels that are common to other studies (e.g., WMO, 2014; Steinbrecht et al., 2017) to facilitate comparisons.*

A new approach to error assessment of Level 2 satellite data is being developed under the SPARC "*Towards Unified Error Reporting* (TUNER)" activity. Also, ozone record uncertainties are addressed in other SPARC activities. Standardized error budgets have also been defined within NDACC and are in the process of being included in the data records. The common statistical linear regression trend model used here was optimized for analyses of the zonally averaged satellite data sets. However, analyses of the ground-based data require reconsideration of additional proxies and optimization methods to improve the interpretation of the processes that impact ozone changes over limited geophysical regions and reduce trend uncertainties.

A first attempt to evaluate representativeness of the trends derived from ground-based station records in the middle and upper stratosphere using SBUV data was done as a part of the LOTUS activity and is discussed in the report. Comparisons of trends derived from satellite data sub-sampled at the station location to those derived from the relevant zonal average provide a measure of potential sampling errors when comparing satellite-based and ground-based trends.

The future CCMI Model retrospective runs need to be designed with a focus on verification of simulated trends. A larger number of simulations should be used to produce realistic ozone variability associated with both chemistry and dynamical transport mechanisms. An assessment of model sensitivities to uncertainties in the volcanic aerosols, solar cycle, QBO, ENSO and other mechanisms also needs to be considered in the model simulation tests. In the LOTUS report, the ozone trends are analysed at low and middle latitudes, with a focus on the upper and middle stratosphere. Future work will include assessing trends in polar regions and in the lower stratosphere, in conjunction with the SPARC activity OCTAV-UTLS. OCTAV-UTLS is dedicated to the assessment of the composition of the upper troposphere and lower stratosphere (UTLS) and identification of atmospheric processes that impact UTLS changes on decadal scales. Similarly, the trends derived from total column ozone data are also left for future work.

Assessments as reported here need to be regularly repeated, preferably in collaboration with other SPARC and WMO/GAW activities. The LOTUS report has recently been accepted after peer review. It will be published in autumn and be available at **www.sparc-climate.org/publications/sparc-reports/**.

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News: Assessment planned for unexpected increase of CFC-11

Paul A. Newman (co-chair, UNEP/WMO Scientific Assessment Panel; **Paul.A.Newman@nasa.gov**)
Neil Harris (co-chair, SPARC Scientific Steering Group; **neil.harris@cranfield.ac.uk**)

The Montreal Protocol was designed to protect the stratospheric ozone layer by reducing the abundances of ozone depleting substances such as chlorofluorocarbons (CFCs) in the atmosphere. In a recent letter to *Nature*, Montzka et. (2018) reported an unexpected and persistent increase in the global emissions of CFC-11, effective for ozone-depletion and a powerful greenhouse gas. The study combines decade-long time-series of CFC-11 from various continents with a suite of two- and three-dimensional model simulations including trajectory analyses. It concludes that the calculated increased CFC-11 emissions arise from new production not reported to the UNEP's Ozone Secretariat.

In response, the Parties to the Montreal Protocol have begun to take action. At their 40th Open-ended Working Group in Vienna (July 2018), they began negotiating a request for their Scientific Assessment Panel (SAP). It is expected that the Parties will soon ask for a report on the unexpected increase of CFC-11 emissions. In order to develop such a report, the SAP co-chairs, UNEP, GAW and SPARC are discussing an initiative to hold a scientific symposium on CFC-11 in March 2019, with details to be agreed in the next few months. These details will be posted on the SPARC website.

Montzka, S.A. *et al.*, 2018: An unexpected and persistent increase in global emissions of ozone-depleting CFC-11. *Nature* **557**, 413-417.

SPARC SOLARIS-HEPPA working group meetings

Rémi Thiéblemont[1,a], Katja Matthes[2,3] and Bernd Funke[4]

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Dates:
6-9 November 2017, Paris, France
&
23-24 April 2018, Karlsruhe, Germay

Organisers:
Rémi Thiéblemont (Laboratoire Atmosphères Milieux, Observations Spatiales, Paris, France ; now at Laboratoire des Sciences du Climat et de l'Environnement, Saint-Aubin, France).
&
Thomas Reddmann (KIT Karlsruhe, Germany)

Host Institutions:
Laboratoire Atmosphères Milieux, Observations Spatiales, Paris, France
&
Karlsruhe Institute of Technology

Number Of Participants: **42 & 12**

Sponsors:

Workshop Website:
http://solarisheppa.geomar.de/paris2017

The SPARC SOLARIS-HEPPA working group meeting was held from the 6th to the 9th of November 2017 in Paris. It was organized by the Laboratoire Atmosphères Milieux, Observations Spatiales on the campus of the Université Pierre et Marie Curie. 42 participants from 13 countries attended the workshop to present and discuss the first results of the five new working groups (**http://solarisheppa.geomar.de/working-groups**), which have been defined to coordinate the analysis of the impact of solar variability (irradiance and energetic particles) on the atmosphere and climate in simulations of the Chemistry-Climate Model Intercomparison (CCMI) project. The focus of the workshop was on the analysis of solar signals in CCMI experiments and their comparison with observational results. More general contributions related to solar influence on climate, not specifically linked to the CCMI analysis, were also presented. The workshop combined 4 invited talks, 4 working group overviews and 20 individual oral contributions.

After a welcome from the local organizing committee (**Philippe Keckhut & Rémi Thiéblemont**) and a brief presentation of the new working groups (**Katja Matthes & Bernd Funke**), **Urs Baltensperger** gave an overview of the main objectives, the measurement principle and the most exciting results of the Cloud chamber experiment at CERN. In particular, they explored possible influence of cosmic rays on climate. He showed that the recent Cloud chamber experiments do not allow for the conclusion that cosmic ray intensity variations create a significant climate effect through nucleation and cloud cover modulation in the present-day atmosphere.

Working group on the surface signal

An overview of the preliminary results of working group 2, which examines the surface solar signals in historical (1960-2010, REF-C1) and future (2010-2100, REF-C2) simulations, was presented by **Klairie Tourpali**. The surface response to the 11-year solar cycle was also diagnosed in various atmospheric and ocean reanalyses datasets. All reanalyses show a warmer troposphere under solar maximum conditions. Although uncertainties remain on the timing of the response, a most likely time lag of 1-2 years is evidenced. The working group 2 overview was followed by individual oral contributions that focused on the surface response to solar variability and the role of ocean-atmosphere couplings.

Katja Matthes presented a synchronization of the NAO with the solar cycle 1-2 years after the solar maximum in CESM-WACCM model experiments. She highlighted that the stratospheric top-down mechanism as well as atmosphere-ocean interactions are key ingredients to reproduce this observed regional solar surface signal. Based on historical SST datasets, **Kuni Kodera** then showed evidence of a nonlinear response of the Pacific sea surface temperature (SST) to the 11-year solar cycle. He proposed that the non-linear response to the solar cycle over the Pacific Ocean can be attributed to the enhancement of cross-equatorial southerlies associated with a northward shift of the rising branch of the Hadley cell during boreal summer. Further analysis of the Pacific response to the solar cycle was presented by **Wenjuan Huo**. She suggested complex mechanisms, implying ocean teleconnection, air-sea interaction and convection-cloud feedbacks, which could be responsible for the El-Niño Modoki modulation by solar activity. This modulation also peaks about 2 years after the solar maximum (similar to the NAO in the Atlantic). **Tim Kruschke** concluded this session by presenting preliminary results of a study examining solar induced decadal climate variability in very long (> 500 years) simulations with the fully coupled chemistry-climate model CESM(WACCM), where different amplitudes of the solar cycle were prescribed. Although consistent atmospheric dynamical responses to solar variability (e.g. stronger Arctic polar vortex under solar maximum conditions) in the different experiments were found, the amplitude of the signals does not linearly change with the amplitude of the forcing. The results further suggest a dependence of the solar signal on background conditions.

Working group on the stratospheric signal

The second day of the workshop started with an invited contribution of **Mustapha Meftah** who presented recent solar spectral irradiance (SSI) observations from space by the SOLSPEC instrument. This instrument was used for the determination of a new reference solar spectrum that extends until 3000 nm (Meftah *et al.*, 2017) and for estimating the SSI variability over the period 2008-2017 (covering the last solar maximum). **Markus Kunze** and **Gabriel Chiodo** followed with an overview of the preliminary results of working group 1, which examines the stratospheric response to solar spectral variability in REF-C1 and REF-C2 CCMI simulations. The solar signal in temperature and ozone was extracted from a multiple linear regression (MLR) model. The solar signal shows significant inter-model discrepancies which remain to be diagnosed and quantified in future analysis. Using sensitivity experiments with two CCMs (EMAC & WACCM), they further showed that the solar signal in the upper stratosphere/stratopause is significantly influenced by the SSI dataset, while the lower stratospheric/upper mesospheric response, mainly depends on the CCM formulation. Still based on MLR methods, **Klairie Tourpali** explored the solar cycle signal in the vertical ozone distribution from REF-C2 simulations in comparison with satellite and ground-based observations. These analyses where conducted as part of the LOTUS SPARC activity. Finally, **Yuhji Kuroda** examined the stratosphere/troposphere coupling mechanisms and their influence on climate associated with the 11-year solar cycle by comparing reanalysis and a 165-year simulation of the Earth system model MRI. The results show that the wintertime NAO and the early winter meridional temperature gradient near the stratopause tend to change with the solar cycle, suggesting a significant role of the Polar-Night Jet Oscillation (PJO) on the downward propagation of the solar signal to the North Atlantic area.

Working group on the comparison with (satellite) observations

The results of the working group 3, whose aim is to compare the observed solar signal resulting from solar irradiance and particle forcing in the specified dynamics experiments covering the satellite era from 1980-2010 (CCMI REF-C1SD), were presented in several individual contributions. **Aleš Kuchař** started by showing that in REF-C1SD, the tropical temperature response to the solar cycle (retrieved from a MLR model) depends on the source and the vertical extent of the nudged data. He also found that the double-peaked stratospheric tropical solar signal is more pronounced in models nudged to ERA-I or MERRA. Finally, he emphasized on the volcanoes/solar aliasing effect, which can alter the amplitude and significance of the derived solar signals: this aliasing effect appears more pronounced in the analysis of REF-C1SD than in the REF-C1 experiments (i.e. hindcasts). **Amanda Maycock** then presented the analysis of the solar ozone response (SOR) in CCMI models in comparison with the Bodeker Scientific database, the SPARC/AC&C database for CMIP5, and the SPARC/CCMI database for CMIP6 (Maycock *et al.*, 2018).

The results reveal substantial differences in the representation of the SOR between the CMIP5 and CMIP6 ozone databases. The water vapour response to the solar cycle in CCMI REDC1-SD simulations and satellite observations was presented by **Pavle Arsenovic**. He analysed two periods: 1991-2005 (HALOE), covering the upper stratosphere/mesosphere, and 1992-2012 (HALOE & MIPAS merged), covering the lower stratosphere. MLR results revealed that in the lower polar stratosphere only one CCMI model (EMAC) simulates a significant increase of water vapour similar to observations from HALOE+MIPAS. In the polar mesosphere, however, most models show a decrease in water vapour with increasing solar activity, in agreement with HALOE observations. The session was then followed by a plenary discussion regarding working groups 1, 2 and 3 and future coordinated analysis.

Working group on Medium Energy Electrons (MEE) Model-Measurement intercomparison

The session related to the impact of energetic particle precipitations (EPPs) and working group 5 (i.e., impact of Medium-Energetic Electrons (MEE) on the mesosphere) was introduced by an invited talk of **Annika Seppälä** who gave a review of the current understanding of the EPP influence on the Earth's middle atmosphere and climate. An overview of the working group 5 activities was then provided by **Miriam Sinnhuber**. Their main objective is to compare available forcing estimates for electron precipitation impacting the mesosphere and thermosphere (e.g., CMIP-6 forcing with other data sets), as well as model results including MEE in the mesosphere and lower thermosphere. They also aim to identify the relative contributions of MEE and auroral electrons in the mesosphere and lower thermosphere. **Pekka Verronen** presented the results of a modelling study, based on the WACCM model, designed to investigate the middle atmosphere wintertime polar ozone response to EPPs at decadal timescales. The results revealed that EPPs increase mesospheric ozone variability by 9 to 15% at 70-80 km on decadal scales in both hemispheres. At the same time, significant impacts on stratospheric ozone are mostly limited to the Southern Hemisphere (8% at 35 km). The study further stressed the importance of accounting for the MEE contribution. In this regard, **Joshua Pettit** presented a study which evaluates MEE datasets by comparing WACCM results with satellite observations. Two MEE datasets were tested: one designed by E. Peck and another created by an ISSI team led by Dan Marsh (**http://www.issibern.ch/teams/stratosphericozone/ISSI/Welcome.html**). Both datasets are based on MEPED-POES measurements. The results showed that Peck's (ISSI) dataset likely overestimates (underestimates) ionisation rates associated with MEE and both datasets present some discrepancies in the representation of MEE-generated NO_x compared to observations. This is possibly linked to the representation of middle atmosphere dynamics in the model.

Figure 3: *Participants of the SOLARIS-HEPPA Meeting in Paris, France.* *(Photo: Marco Gaetani, LATMOS)*

On Wednesday morning, the working group 5 session re-started with a study led by **Miriam Sinnhuber** which compared the indirect particle impact in three global models with specified dynamics: 3dCTM, KASIMA (high-top model) and EMAC (medium-top model, which requires the use of an upper boundary condition to account for the transport of NO_y-produced EPP into the model domain). The response in the three models is largely consistent near the mesopause region, but not in the lower mesosphere and stratosphere. These discrepancies are attributed to differences in vertical advection related to different gravity wave drag parameterization. For the O_3 response, the comparison of nudged model experiments of the three models and the MIPAS observations revealed systematic discrepancies that are not related to the geomagnetic forcing. The impact of the gravity wave scheme on polar winter NO_y descent in EMAC was further tested by **Stefan Versick** who found that a better agreement between the model results and mesospheric satellite observations is obtained when the standard Hines parameterization is damped. Employing the Yigit-Medvedev parameterization also yields good agreement with observations in the upper mesosphere. **Thomas Reddmann** then reported progress in parameterizing mid-energy electrons in the KASIMA model and presented the impact on polar NO_y. **Hidle Nesse Tyssøy** then presented a study of the direct (i.e., chemical) and indirect (i.e., transport-related) electron precipitation effect on nitric oxide (NO) during the April 2010 electron precipitation event in the AIM-SOFIE observations and in WACCM. The model results indicate that NO can be directly produced down to ~60 km in the mesosphere. Still, at this altitude the NO response is also influenced by vertical transport (indirect effect) from NO initially produced at ~75 km. The comparison to observations, however, revealed a deficit of NO at altitudes around 90-110 km. Further, no direct NO production below 80 km could be identified from observations. The comparison also stressed the need to account for MEE. **Astrid Haderlein** presented an inter-comparison between the CMIP-6 MEE forcing and the losscone electron fluxes estimated from MEPED/POES. Finally, an update of the model for 30–1000 keV radiation belt driven electron precipitation was described by **Max van der Kamp** . The model is based on precipitation data from low-Earth orbiting satellites POES in the period 2002-2012, and empirically described plasmasphere structures, which are both scaled to Dst or Ap geomagnetic indices. Because this geomagnetic index is the only input of the model, the model can be used to calculate the energy-flux spectrum of precipitating electrons over long periods with a time resolution of 1 day. Model updates include improvements in the noise-floor treatment that allow for a more realistic representation of low electron fluxes during geomagnetically quiet times and include the consideration of magnetic local time effects. **Hauke Schmidt** tested the climate impact of polar mesospheric and stratospheric ozone losses due to EPP in an idealized 150 years simulation with the MPI-ESM model. Despite the strong ozone loss prescribed in the model, they only found little influence on the atmospheric circulation and surface climate in Northern Hemisphere winters. These results questioned the effectiveness of the EPP-induced ozone loss and its impact on polar stratospheric heating rates that have been proposed to be part of the chain of the mechanism leading to the surface response associated with EPPs. Modelling results of particle precipitation impacts on nitric acid using the WACCM-D model and focusing on the EPP events of spring 2010 were then presented by **Yvan Orsolini**. His results stress that EPP generates chemical perturbations in a variety of species (not just NO_x, but also several species of the nitrogen family) and highlight the important role of ion-ion cluster recombination. The session was then followed by a plenary discussion regarding working group 5 and the analysis of EPP-induced signals in CCMI simulations.

Working group on methodological analysis

The workshop ended on Thursday morning with the working group 4 session, which focused on analytical methods used to retrieve the solar signal. **Aleš Kuchař** started by describing the X-regression tool (available online **DOI:10.5281/ZENODO.159817**), which allows performing MLR calculation in flexible configuration and on large datasets, such as CMIP6. Preliminary results of the Methodological Analysis for Solar Signal Identification (MASSI) activity were then presented by **Will Ball** and **Rémi Thiéblemont**. MASSI aims at testing different analytical methods employed to detect and attribute solar signals in observations and models, identifying the limitations of these methods and, possibly, making recommendations.

Figure 4: *Participants of the SOLARIS-HEPPA Working Group Meeting, in Karlsruhe, Germany. (Photo: Katja. Matthes, GEOMAR)*

The meeting ended with a general discussion on the next steps of the working group activities, publication plans, and internal coordination. It was decided to hold a follow-up WG leader meeting in Karlsruhe (see below) in early 2018 in order to coordinate the next actions of the activity.

Group leaders meeting in Karlsruhe, 2018

The SPARC SOLARIS-HEPPA working group leaders meeting with 12 participants was held from the 23rd to the 24th of April 2018 at the Karlsruhe Institute of Technology, organized by Thomas Reddmann.

The first MASSI action was to produce artificial ozone time series (or MOCKS, mimicking stratospheric ozone time series at various locations), constructed from a linear combination of basis functions (QBO, ENSO, …) and by adding data gaps, different trend terms, autoregressive processes, as well as various levels of noise. These MOCKS were then used to test MLR codes of various complexities, that are employed and/or developed by SOLARIS-HEPPA participants for solar signal detection and attribution. The results revealed a good consistency between the various codes, but also allowed for the identification of possible caveats in the use of MLR to retrieve the solar signal. Finally, the Solar-North Atlantic Oscillation (NAO) relationship was revisited by **Gabriel Chiodo**, who compared two long term integrations (500 years) of the WACCM4 model: one with a prescribed solar cycle forcing and one with a constant solar forcing. The comparison of the two experiments revealed that an apparent robust solar-NAO signal can be obtained even in an experiment without variable solar forcing. It was concluded that the observed Solar-NAO relationship may simply arise by chance due to intrinsic NAO decadal variability.

During the three days, contributions not directly linked to the focus of the five working groups were also welcome. **Dmitry Kulyamin** presented modelling results of the lower and middle atmosphere global coupling based on the INM RAS atmospheric general circulation model. **Tobias Spiegl** investigated the global and regional climate impact of a Grand Solar Minimum scenario in simulations of the EMAC model coupled to an ocean.

Only leaders and co-leaders of the five working group attended this one-and-a-half-day meeting to present and discuss their most recent advances on the analysis of solar signals in CCMI experiments, coordinate data sharing, and discuss publication plans. The meeting was aimed to favor discussions and interactions between the different WGs and two hours were allocated for the presentation of the each WG progresses.

Acknowledgements

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We acknowledge WCRP/SPARC for kindly providing travel support to Rémi Thiéblemont to cover travel and accommodation costs for the entire meeting in Karlsruhe.

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Data analysis workshop on the Balloon measurement campaigns of Asian Tropopause Aerosol Layer

M. Venkat Ratnam[1], Jean-Paul Vernier[2] and T. Duncan Fairlie[3]

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Date:

1-2 February 2018

Organisers:

Indian Space Research Organization, National Atmospheric Research Laboratory, National Aeronautics and Space Administration

Host Institution:

National Atmospheric Research Laboratory, Gadanki, India

Number Of Participants: 34

Sponsors:

Atmospheric aerosols play a crucial role in weather and climate. The discovery of an elevated aerosol layer forming every summer over the South Asian Monsoon region is a puzzling phenomenon triggering research work throughout the world. The Asian Tropopause Aerosol Layer (ATAL) was discovered in the early 2010's through satellite observations from the Cloud-Aerosol Lidar and InfraRed Pathfinder Satellite Observations (CALIPSO) and confirmed by the Stratospheric Aerosol and Gas Experiment (SAGE) II. To shed light on the micro-physical and chemical properties of the ATAL, several balloon-borne experiments have been conducted under a NASA-ISRO collaborative program known as the Balloon measurement campaigns of Asian Tropopause Aerosol Layer (BATAL). The BATAL deployments took place at several places in India and Saudi Arabia since 2014 and resulted from collaborative endeavors between the National Atmospheric Research Laboratory (NARL), NASA Langley Research Center, the balloon facility of the Tata Institute of Fundamental Research (TIFR), in Hyderabad, the Banaras Hindu University (BHU) in Varanasi and the Physical Research Laboratory (PRL) in Ahmedabad, as well as the King Abdulha University for Science and Technolofy (KAUST) in Thuwal, Saudi Arabia. The BATAL campaigns benefited from extensive ground-based infrastructures at NARL using radars and lidars from Gadanki (South India). Balloon-borne and ground-based data have been gathered since 2014 (Vernier *et al.*, 2017) and scientists from NARL, NASA (USA), CNRS (France), and other national institutes and universities met at NARL, Gadanki in a two-day workshop between 1-2 February 2018. The goals were to summarise the findings from the past campaigns and to plan for future course of action to address the scientific issues and the implications of the ATAL on weather and climate.

More than 30 scientists from different institutions gathered for the first time for a two-day data analysis workshop. After giving an overview of the BATAL campaigns, the first advanced physical and chemical properties of the ATAL derived from balloon-borne measurements and the links with deep convection during the Asian Summer Monsoon (ASM) were presented. One of the major findings came from the chemical analysis of aerosol samples and the detection of nitrate particles within the ATAL region (**Dr. J.-P. Vernier**). Light weight Aerosol Optical Counter (LOAC) observations within the ATAL revealed the likely presence of particles with an absorbing signature indicating the possible presence of carbonaceous aerosol of sub-micron size (**Dr. G. Berthet**). An important objective of the BATAL campaign is to shed light on cloud-aerosol interaction in UTLS region during the ASM.

Figure 5: *Participants of the BATAL workshop held at NARL, India.*

Balloon measurements have shown the existence of ice layers in the lower stratosphere connected with convective overshooting (**Dr.Saravan Kumar**). Model simulations using WRF-Chem point out South China, Northern part of the Bay of Bengal and the Indo Gangetic Basin as principal source regions for the production of sulphates and nitrates, two major constituents of the ATAL in the UTLS.

Dr. V. Ravikiran presented cloud observations by the Cloud Particle Sensor(CPS) sonde together with space-borne and ground-based Lidar. Most observations (ground-based, balloon- and space-borne) show the frequent occurrence of cirrus cloud within the 10-18 km altitude range where the ATAL layer was observed during the BATAL campaigns (**Dr. Amit Pandit**). Inter-comparison of aerosol parameters between Compact Optical Backscatter AerosoL Detector (COBALD), ground based Lidar (BLL) and CALIPSO showed very good consistency among the measurements (**Mr. P. Prasad**). Several challenges still remain in getting information on Black Carbon profile (**Dr. Harish Gadhavi**).

Simulations conducted with the GEOS-Chem transport model show sulphate-nitrate-ammonium, and organic aerosol within the ATAL with dominant sources from Eastern China and North India (**Dr. T. Duncan Fairlie**). Indian emissions were found to contribute up to ~30% of sulphate in core of the ASM anti-cyclone while Chinese emissions contributed another ~30% for the case studied. In contrast, Neely *et al.* (2013) found that only 30% of sulphate in the ATAL originate from India and China together. Significant inter-annual and intra-seasonal variability in source contributions to ATAL were noted. However, chemical analysis measurements during BATAL 2017 using a balloon-borne impactor system developed at NASA Langley show the presence of nitrate and nitrite containing particles as well as the presence of trace metal ions but surprisingly no sulphate was detected (**Dr. N. Rastogi**). A regional chemical transport model WRF-Chem coupled with meteorology from NARL showed the presence of aerosols and CO in the upper troposphere within the ASM anticyclone region (**Dr.Vikas Singh**). Model simulations show that deep convection during the ASM play the main role in lifting anthropogenic emissions up to the upper troposphere and lower stratosphere (**Dr. Jyothi Bhate**).

Presentations during the BATAL workshop also focused on free tropospheric aerosol layers during the monsoon and their connections with the ATAL. The existence of an elevated aerosol layer, above the Boundary Layer, during the ASM was observed with ground-based lidar observations from Gadanki. Long-range transport through the Low Level Jet was deduced using trajectory calculations (**Dr. M. Venkat Ratnam**). Rain water samples collected over Gadanki and further analysed with Ion Chromatography point out the influence of dust emitted from the Arabic Peninsula (**Dr. Chaithanya D. Jain**). Deep convection persisting over the head of the Bay of Bengal can influence the transport of troposphere pollutants to the UTLS region. MST radar from Gadanki revealed upward vertical velocities during ISM in the free troposphere (**Dr. S. Ravindra Babu**). Aerosols over Gadanki can either originate from local convection or transport over long-distance from other sources (e.g. Eastern China). During the monsoon season, primary aerosols are likely removed from the atmosphere through rainout or washout mechanisms. The existence of strong vertical shears of the horizontal wind during the monsoon can also restrict the vertical transport. Nevertheless, long-term Mie lidar observations from Gadanki suggest the presence of aerosols in the UTLS region (**Dr. B.L. Madhavan**). The presence of the Anti-cyclonic flow in the UTLS region makes the confinement of aerosols and trace gases possible. They can be re-distributed to other regions of the world through Hadley and Walker circulations. Significant influence of QBO and ENSO on the ATAL is also noticed using long-term measurements (**Dr. Ghouse Basha**). Thus, dynamics likely play a major role in the formation and maintenance of the elevated aerosol layers. Radiative forcing due to these aerosols and its effect on cirrus and water vapour need to be estimated. Quantifying the source regions responsible for the formation of the ATAL is important.

BATAL workshop Recommendations

A series of recommendations have been raised by different participants of the Workshop. It includes :

1. The modification and development of new instruments. The discovery of nitrate-containing particles and the absence of sulphate (though limited sampling) in the balloon observations raises important new science questions which needs to be addressed in the future. Could natural sources (e.g. lightning) be an important driver for the ATAL? Are sulphate particles completely removed during convective transport before reaching the UTLS, or was the sampling of ATAL by the balloon flights too limited? In order to address some of those questions, the BATAL group recommended additional zero-pressure experiments with longer duration flights and/or higher sampling rate to collect larger concentrations of aerosols and improve the retrieval of minor species that might be present. In addition, the presence of nitrate aerosol points out the roles of NO_X/NO_Y chemical species as gas-precursors. The BATAL group recommend the development of a balloon-borne payload capable of measuring those species.

2. Extend balloon launch sites and Ground-based network. The BATAL science team recognized the need to establish Ground-based lidars over North India (eg. Kolkata University and/or Bose Institute, Kolkata, ARIES, Nainital) operating with multiple wavelengths (355 nm, 532 nm, 1064 nm) and with polarization measurements (532 nm) to differentiate aerosol types and ice clouds. The new BATAL network should also include other countries. Giving the existing of balloon activities in China, a rapprochement between BATAL and this activity is needed.

3. High altitude aircraft measurements. The BATAL recognizes the importance of continuing balloon-borne measurements but also admit their limitations. In order to address some of the science questions related to the physical and chemical composition of the ATAL and its impact on stratospheric ozone and cirrus clouds in the TTL, our team recognizes that airborne measurements at high altitudes (14-20 km) from South to North India across the Asian anticyclone as well as near principal source regions (North East India, Indo-Gangetic Plain) would only be possible via aircraft measurements. The group recommends continuing airborne sample collection for laboratory chemical analysis and in situ optical measurements. Towards a future proposal to carry out an airborne campaign covering the UTLS region, a cost sharing agreement between NASA and ISRO will be discussed. In addition, a list of instruments will be identified for this future aircraft mission.

4. Data sharing, science team and external communication. The BATAL group highlighted the need to improve the communication between the science team by forming a common mailing list. In addition, a web site and a server where data can be shared should be put in place. We also need to explore the possibility of reaching wider scientific community to share the findings on ATAL through AGU/COSPAR/SPARC/NSSS meetings

Figure 6: *Photo of the launch preparation during the BATAL winter campaign conducted at TIFR Balloon Facility between 5-13 February 2018. The scientific package flown under a 3000 m^3 polyethylene balloon included 10 different payloads mostly dedicated to study clouds and aerosols.*

BATAL 2018

After the BATAL workshop, a test campaign at TIFR Balloon facility, Hyderabad, was conducted between 5-13 February 2018 to compare and contrast summer measurements. New aerosol and cloud sensors have been tested.

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SPARC workshop "The UTLS: current status and emerging challenges"

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Dates:

5-8 February 2018

Organisers:

Peter Hoor, Daniel Kunkel, (Johannes Gutenberg University, Mainz, Germany)

Host Institution:

Institute for Atmospheric Physics, Johannes Gutenberg University, Mainz, Germany

Number Of Participants: ~110

Sponsors:

SPARC, WCRP, Johannes Gutenberg Universität Mainz

Workshop Website:

https://converia.uni-mainz.de/frontend/index.php?sub=59

Although the knowledge on the Upper Troposphere / Lower Stratosphere region (UTLS) increased substantially over the last decade, important uncertainties remain on key topics of long-term variability and trends, feedback mechanisms between dynamics and chemistry, and mechanisms of two-way stratosphere troposphere coupling. Trend estimates of e.g. ozone (Ball *et al.*, 2018, Steinbrecht *et al.*, 2017) or water vapour (e.g. Hegglin *et al.*, 2014) are under debate illustrating gaps of our current understanding of the UTLS. The effect of mixing on radiatively active species in the UTLS is difficult to quantify in current state-of-the-art climate models (Riese *et al.*, 2012), since the distribution of the relevant species crucially depends on parameterizations of sub-grid processes.

The goal of this workshop was to summarize the current knowledge, to identify gaps of current understanding, and to provide directions for future UTLS research. The last UTLS community workshop was in Boulder (2009) and the current workshop in Mainz can be seen in the tradition of previous workshops in Mainz (2005) and Bad Tölz (2001). It comprised keynote talks, contributed talks, and a poster session over three days. During the four day workshop at the Johannes Gutenberg University in Mainz, Germany, more than 110 scientists from different fields linked to, and thus with different perspectives on, UTLS research discussed the current status of ongoing UTLS research.

The workshop was subdivided into six major topics starting with (1) aerosol and ice clouds, (2) the TTL region (3) dynamics and circulation changes (4) the extratropical tropopause including gravity waves, (5) composition and trends as well as (6) future perspectives. **Peter Hoor** opened the meeting and gave an overview on the developments since 2009 focusing on key improvements, but also addressing the major uncertainties.

Aerosol and Ice clouds

The regular part of the meeting was opened by **Dan Murphy,** who showed that the aerosol in the lowermost stratosphere is a mixture of organic and sulfate particles and that the radiative forcing of the stratospheric aerosol is larger than previously thought. Presenting new measurements from two WB57 campaigns (POSIDON, Guam 2016 and VIRGAS, California, 2015), **Andrew Rollins** showed the importance of aerosol formation in the TTL for the stratospheric sulfate, with typically 10-200pptv of SO_2 below the tropopause at 17 km.

At mid-latitudes meteoric material contributes significantly to the UTLS aerosol composition as shown by **Johannes Schneider** presenting single particle analyses from the ML-CIRRUS campaign (Western Europe, spring 2014). He also highlighted the different composition of cirrus residuals from liquid and in-situ origin. **Christiane Voigt** summarized key results from ML-CIRRUS indicating larger numbers of small ice particles in contrail cirrus compared to the natural background and pointing out the importance of vertical transport in warm conveyor belts for the cirrus formation. The afternoon session continued the aerosol topic, initially focusing on processes related to the Asian summer monsoon (ASM) and presenting results from the STRATOCLIM campaign in Nepal in summer 2017. **Stephan Borrmann** confirmed the outstanding role of the ASM as the most significant aerosol source for the summertime UTLS up to 420 K, also including new particle formation events and the role of non-volatile particles which make up about half of the sub-micron aerosol mass. **Martina Krämer** reported on the occurrence of high number concentrations of ice particles at very cold tropopause temperatures and altitudes in the ASM and of supersaturated cirrus up to 400 K which potentially moisten the UTLS. In addition to the airborne measurements, balloon measurements inside the ASM revealed the importance of convection for water vapour and supersaturation in the region above the monsoon tropopause, but still inside the anticyclone (**Simone Brunamonti**). **Troy Thornberry** then came back to POSIDON showing compact histograms of ice water content above 16.5 km in the TTL and their link to tropical convection. The first session ended with a talk by **Stefan Fueglistaler** who presented a new approach to determine water fluxes to better understand the moisture content of the lower stratosphere based on theoretical considerations and CALIOP observations.

Dynamics and chemistry related to the Asian Summer Monsoon

The last session on the first day was started by a talk of **Mohamadou Diallo** on the impact of volcanic aerosol on the strength of the Brewer Dobson circulation (BDC). In a series of talks further studies on the impact of the ASM on the composition of the lower stratosphere were presented. **Michael Volk** showed new insights on horizontal and vertical transport processes within the ASM based on in-situ measurements of long-lived trace species during STRATOCLIM. A large scale overview about the chemical composition of the UTLS inside the ASM was presented by **Michael Höpfner**, based on airborne remote sensing measurements with the GLORIA instrument. Two main transport time scales characterize export of air from the ASM into the stratosphere as shown by **Felix Plöger**. Short timescales dominate transport into the extratropical lower stratosphere, but long time scales for export into the tropical pipe. The session was concluded by two talks about the impact on the chemical composition of the extratropical UTLS after the break-up of the anti-cyclone. First, **Christian Rolf** reported on enhanced concentrations of water vapour and methane in the lower stratosphere during TACTS (Western Europe, 2012). Here, water vapour increased by about 0.5 ppmv and methane by 24ppbv during the break-up phase of the ASM. Finally, **Jörn Ungermann** showed an example on how water vapour anomalies in the extratropical UTLS can be linked to multiple Rossby wave breaking events and long range transport along the subtropical jet during the WISE campaign.

Tropical tropopause layer

Tuesday morning started with tropical tropopause layer (TTL) and water vapour topics. In the first talk, **Laura Pan** highlighted the importance of horizontal transport in the tropics for the interpretation of dehydration and the relation to the Lagrangian Cold point and the lapse rate tropopause. The anomalously dry stratosphere during 2016 was addressed by **Dale Hurst** who concluded that this was caused by a synchronization of the exceptional stratospheric QBO and ENSO which led to cold tropical tropopause, except over the tropical central Pacific (moderately cold and dry). With the goal to better understand the large spread in TTL temperatures in the CCMVal2 model simulations **Thomas Birner** then showed how the interaction of upwelling and water vapour and ozone radiative feedbacks affect the temperature and altitude of the tropical tropopause. **Alison Ming** also addressed TTL temperatures using ERA Interim data and three different methods to estimate tropical upwelling. She concluded that the seasonal cycles of temperature and upwelling are well related, but with large quantitative differences between the various methods. Causes for the variability of tropical upwelling in CMIP5 models were presented by **Kohei Yoshida**. He pointed out that the upwelling mainly depends on tropical planetary-scale and extratropical synoptic-scale waves but also on parameterized gravity wave drag with strong implications for future scenarios.

Stratosphere-troposphere coupling

The late morning session started with **Ted Shepherd** talking about open issues on stratosphere-troposphere coupling (STC) and the impact on the tropospheric circulation on various time scales. In particular, he stressed the lack of understanding in the processes leading to STC as well as the application of methods to detect the coupling and the impact on e.g., the European climate. **Chaim Garfinkel** highlighted the non-linearity of coupling between ENSO and lower stratospheric temperatures and water vapour with the main conclusion being that strong ENSO events lead to warming and moistening. ENSO also affects the ASM anticyclone with a weaker circulation associated with strong El Nino events but a stronger Hadley circulation and stronger in-mixing of ozone into the tropics following La Nina (**Xiaolu Yan**). The effect of ozone on the TTL temperature structure was shown by **Ed Charlesworth** using a simple radiative and photochemical equilibrium model. As a final talk on Tuesday morning **Mengchu Tao** emphasized the role of isentropic mixing to explain lower tropical tropospheric ozone concentrations.

A central part of the meeting was the poster session on Tuesday, which constituted of more than 50 posters. These were on display from Monday to Wednesday to allow for sufficient time for discussions.

Stratospheric circulation

The afternoon session started with **Marta Abalos**, who discussed the importance and consequences of future climate change on transport and mixing and the tropopause location using an e90 tracer. Trends of tropical upwelling in the lower branch of the BDC were presented by **Hella Garny** showing agreement between reanalysis and climate models for historical periods with strongest increases in upwelling at 70 hPa in DJF and 100 hPa in JJA. **Dieter Peters** presented a link between the NAM150 index and a downward propagating signal and tropospheric impact 8-50 days after the event, potentially enhancing climate predictability. Juan Anel (talk by **Petr Sacha**) compared the expansion of the tropics in reanalyses and WACCM simulations using isentropic PV fields and age of air showing large variability of the expansion signal. New possibilities of observations of stratospheric age of air were presented by **Andreas Engel**. He introduced the new balloon borne AIRCORE sampling, which provides an inexpensive opportunity to extend the measurement time series in the mid stratosphere. A way of deriving age spectra from realistic tracers was presented by **Frauke Fritsch**, showing differences between pulsed and linear tracer experiments and passive SF6.

The extratropical UTLS

Wednesday morning was dedicated to the extratropical tropopause and started with **Heini Wernli**, who highlighted the role of diabatic processes for the tropopause structure and cross tropopause exchange. Particularly, this involves sub-grid processes such as cloud formation, convection and warm conveyor belts, which lead to modification of Rossby waves and the PV structure. The role of turbulence as an important small scale process for redistributing trace species across jet streams in global models was shown by **Holger Tost. Volkmar Wirth** presented a new diagnostic to quantify the propagation of Rossby wave packets (RWP), the 'local finite amplitude wave activity', which allows diagnosing RWPs even in the nonlinear stage, where envelope methods tend to lose the RWP signal. **Andreas Schäfler** presented first results from the WISE mission, showing curtain like water vapour and ozone LIDAR observations which allow identifying different mixing states of air parcels in a tropopause fold. **Robin Pilch Kedzierski** showed the effect of planetary and synoptic waves on the lower stratospheric static stability and concluded that the tropopause inversion layer (TIL) is a result of the tropopause based average of the wave affected tropopause locations. The second part of the extratropical session was opened by **Markus Rapp**, who showed the effect of the TIL for the propagation of gravity waves (GW), which in turn may lead to mixing and trace gas exchange at the tropopause. A detailed analysis of gravity wave propagation through and interaction with the TIL was presented by **Vera Bense**, using idealized simulations to show that the transmission strongly depends on the vertical wavelength and that the waves can alter the TIL as well. As shown by **Aurelien Podglajen**, GWs play a vital role for mixing and vertical transport in the TTL which in some cases can be on the same order of magnitude as vertical upwelling. **Gergely Bölöni** presented a new approach to represent gravity waves in global models, replacing the current steady state parameterization of GWs by one that allows for a more realistic interaction between GWs and resolved flow. **Martin Riese** gave an overview over the WISE mission in September 2017, which focused on mixing processes at the extratropical tropopause, including the influences of fine-scale structures in a tropopause fold.

During the campaign, small scale mixing above a warm conveyor belt was observed. The POLSTRACC mission in winter 2015/2016 was introduced by **Hermann Oelhaf**, who showed that the lower stratosphere was strongly affected by polar stratospheric clouds down to 11km and strong ozone loss down to 400 K.

UTLS trends and composition

Wednesday afternoon started with **Michaela Hegglin**, who talked about recent updates on trend observations in the UTLS with a focus on water vapour and ozone. She pointed out the difficulty to quantify trends in the UTLS due to the strong dynamical variability, as well as the necessity of consistent and precise observations to reduce uncertainties and partly contradicting results of trend estimates. Focusing on ozone trends in the tropical UTLS, **Anne Thompson** showed reprocessed data from SHADOZ which have a higher accuracy than earlier versions. She also pointed out the substantial differences of ozone variability in the deep tropics compared to the subtropical stations. A new clustering technique to compare UTLS ozone from sondes and MERRA-2 reanalysis was presented by **Ryan Stauffer**, allowing to link extratropical ozone profiles to meteorological conditions and tropical profiles to convection and pollution events. **Krzysztof Wargan** also used MERRA-2 data to identify multi-decadal changes of ozone trends in reanalyses. He concluded that negative trends can most probably be linked to enhanced isentropic mixing in the UTLS in MERRA-2 and in M2-GMI simulations. A catalogue of stratospheric intrusions in MERRA-2 was presented by **Emma Knowland**, particularly addressing the importance of these intrusions for tropospheric ozone. **Karen Rosenlof** showed that the North American monsoon convection is not a significant driver of heterogeneous chemical ozone loss in the mid latitude stratosphere. Using MLS observations **Michelle Santee** showed the large variability of the UTLS composition due to the ASM anticyclone. Her study includes latest results from 2017, when the stratospheric moistening by the ASM started earlier, but the pollution inside the ASM was weaker compared to other years. **Rolf Müller** stressed that NO_x is more important for chemical ozone production in the UTLS than infrequent events of high water vapour and simultaneous enhanced HCl and ozone. An analysis of Arctic ozone loss during the very cold winter 2015/2016 was presented by **Björn Martin Sinnhuber**. Based on measurements during POLSTRACC and simulations by CLaMS and EMAC he concluded on ozone loss of 1.6 ppmv at 400 K. The Wednesday session on ozone and composition trends was closed by **Irina Petropavlovskhikh**, who showed results from the LOTUS initiative. Combined satellite, model and ground based data sets indicate an ozone recovery for the post 2000 period in the extratropical stratosphere, but decreasing ozone in the lower UTLS with large uncertainties.

Thursday started with a series of talks about passenger aircraft observations from the IAGOS project. First, **Andreas Zahn** highlighted the gain from combining regular passenger aircraft observations with modelling and reanalysis data to identify e.g. pathways controlling water vapour in the UTLS. **Harald Bönisch** (presenting the contribution by Denise Assmann) addressed the aerosol abundance in the UTLS, indicating that accumulation mode particles are present above the tropopause and that WCBs may act as a source of aerosols in the tropopause region. **Yann Cohen** showed climatologies of CO and ozone in the Northern Hemisphere UTLS from IAGOS data. CO trends (2002-2013) appear to be mostly negative in the northern UT, whereas ozone increases (1994-2013) in the UT, but shows no significant trend in the LS. **Andreas Petzold** summarized findings on the long term water vapour distributions based on combined IAGOS and research aircraft data from the JULIA data base. No significant H_2O trend can be deduced over the North Atlantic, but large seasonal differences of UTLS water vapour distributions indicate significant seasonally varying transport processes affecting water vapour in the UTLS.

The session was closed by **Bill Randel**, giving a summary, outlook, and scientific challenges of the previous days. He emphasized the global view of the tropopause region including the Southern Hemisphere. Open questions concern the extratropical tropopause, which is much stronger affected by diabatic processes than previously thought, and which might substantially affect the lower UTLS composition. Important advances have been made in understanding the role of the Asian summer monsoon anticyclone and its relevance as source region for trace gases and aerosols in the UTLS. However, while the qualitative picture of the UTLS increased in the last years, quantitative estimates of the relevant transport pathways and times are still under debate. Also, the TTL, its coupling to the residual circulation, and the effects of two way mixing across the jets lacks quantitative understanding. Small scale processes, like gravity waves or turbulence, may play an important role for the composition and entry conditions to the BDC.

***Figure 7:** Participants of the UTLS Workshop.* *(Photo: Philipp Reutter, University of Mainz)*

He emphasized the use of long-term measurements and observations in the UTLS to identify uncertainties in trends and link processes and large scale trends.

With this summary, and based on the input by the rapporteurs (**Marta Abalos, Hella Garny, Andreas Petzold, Daniel Kunkel, Tanja Schuck, and Felix Plöger**), the final discussion started. It was led by Peter Hoor and brought out the following questions:

- Can we better quantify trends and variability and their driving processes in the UTLS?
- What roles do diabatic (sub-grid) processes play in the tropopause region for the UTLS composition?
- Which feedback mechanisms on multiple scales affect large scale circulation and climate?
- What are the sources of UTLS aerosol, and what is their contribution to radiative forcing?
- What roles do UTLS processes play for stratosphere-troposphere coupling and extreme weather, and what are relevant coupling mechanisms?

To answer these questions further collaborations across the various sub-communities which actively work on topics related the UTLS were discussed. The community agreed on the need for a continuation of high precision and accurate measurements of ozone and water to better constrain trends. This also holds for the role of aerosols in the UTLS, which may affect the energy budget in many ways. These measurements in combination with new higher resolution reanalysis data are further needed for a quantitative understanding of processes, in particular at the tropopause, which are potentially missed by previous coarse reanalysis data sets.

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Chapman conference on Stratospheric Aerosol in the post-Pinatubo Era: Processes, Interactions and Importance

Stefanie Kremser[1], Terry Deshler[2], Claudia Timmreck[3], and Larry Thomason[4]

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Dates:
18-23 March 2018

Organisers:
Claudia Timmreck (Germany), Larry Thomason (USA), Stefanie Kremser (New Zealand), Jean-Paul Vernier (USA)

Meeting venue:
Puerto de la Cruz, Tenerife, Canary Islands, Spain

Number Of Participants: 73

Sponsors:

Activity Website:
http://www.sparc-ssirc.org/

An AGU Chapman Conference was organized through the work of the scientific steering group of the SPARC Stratospheric Sulfur and its Role in Climate (SSiRC) activity. The conference, convened by Terry Deshler, Larry Thomason, and Mian Chin, was held in Puerto de la Cruz, Tenerife, Canary Islands from 18-23 March 2018. The meeting was attended by 73 scientists, including a number of students and early career scientists, from 15 countries. The conference consisted of oral and poster presentations as well as focused small groups meetings. The scientific focus of the conference was on stratospheric aerosol in the post-Pinatubo era (1996 to the present), a period in which stratospheric aerosol has been at, or near, the lowest levels observed by modern instrumentation. Volcanically quiescent periods are ideally suited to study troposphere-to-stratosphere transport, background stratospheric chemistry, trends in stratospheric sulfate aerosol, and the sources and potential climate impact of non-sulfate stratospheric aerosol including anthropogenic aerosol, organic aerosol, meteoritic dust, and soot from biomass burning. Leading observational and modelling experts in stratospheric aerosol and precursor gases presented and discussed major science questions related to the character and processes controlling stratospheric aerosol during this quiescent to mildly volcanic period and the impact of such a period on stratospheric chemistry and climate.

The first day of the conference focused on the stratospheric aerosol record, including satellite, ground and balloon based measurements. Furthermore, several comparisons of satellite-based measurements (OMI, SAGE, GOMOS, OMPS, OSIRIS) of aerosol properties were presented. **Mike Fromm** opened the conference discussing uncertainties in the volcanic aerosol composition shortly after an eruption suggesting that sulfate aerosols have been present from the beginning and may contaminate UV SO_2 retrievals. **Ghassan Taha** presented an overview of a revised retrieval algorithm for OMPS limb profiling data, which lead to more consistent results in OMPS measurements between hemispheres. **Katherine Foster** found agreement to within 10% when in situ aerosol measurements are compared with OMPS extinction profiles during 12 balloon flights between 2012 and 2015. Results of a new aerosol extinction retrieval algorithm of OMPS measurements in comparison to coincident OSIRIS data and initial results of merging OSIRIS with OMPS measurements were presented by **Landon Rieger**. **Christine Bingen** described particle size distributions at different altitudes down to 15 km as a new data product from GOMOS.

The second session on Monday focused on aerosol in the Upper Troposphere / Lower Stratosphere region (UTLS). **Suvarna Fadnavis** used satellite observations to indicate that during El Niño there is a higher-than-normal aerosol loading over North-India, which influences rainfall over India during the summer monsoon season. **Markus Hermann** suggested that tagging in situ measurements made on-board a passenger aircraft (IAGOS-CARIBIC, **www.iagos.org/iagos-caribic**) according to transport processes provides a unique data source for comparison with remote sensing instruments and global atmospheric models. Model simulations and observations were used in a study presented by **Mian Chin** and the results indicate that even without major volcanic eruptions, volcanic SO_2 emissions seem to dominate aerosol optical depth in the stratosphere over the past 12 years. The invited talk given by **Nickolay Krotkov** provided an overview of satellite retrievals of volcanic and anthropogenic SO_2, indicating that new satellite instruments and multi-wavelength retrieval algorithms reduce the noise in SO_2 retrievals by up to a factor of 10 (from 4 to 0.4 DU). The NASA SO_2 team has a multiyear experience in detecting, tracking and measuring volcanic clouds and anthropogenic SO_2 pollution from space (**http://so2.gsfc.nasa.gov**) and provide a multi-decadal volcanic SO_2 emissions climatology created by combining measurements from sevaral satellites.

The first day's keynote lecture by **Stephan Borrmann,** entitled: "The Tropical Upper Troposphere and Lower Stratosphere: Source Region for Stratospheric Aerosols", provided an overview of the 2017 StratoClim campaign in Kathmandu with a focus on aerosol properties at the gateway to the stratosphere in the tropical UTLS.

The first session on Tuesday focused on non-sulfate sources of stratospheric aerosol. In his invited talk, **Ralf Weigel** presented measurements indicating the contribution of meteoritic material to cloud formation in the middle atmosphere and discussed the role of clouds in removing meteoric material from the middle atmosphere. The North American wildfires in summer 2018 produced smoke plumes clearly visible in ground-based and satellite lidar and UV observations with stratospheric values comparable to a volcanic signal. **Sergey Khaykin** compared CALIOP lidar measurements with ground based lidar data from France, finding excellent agreement. **Omar Torres** reviewed the method used to derive SO_2 abundances from satellite UV measurements and then presented measurements of the 2018 wildfire plumes. Results from a laboratory study of ash/sulfate/ice interactions indicate that ash with a low manganese and titanium content and high potassium content is more effective for nucleating ice, according to **Margaret Tolbert**.

The morning session was concluded by **Graham Mann**, who showed that aerosol of meteoric origin contributes substantially to the stratospheric aerosol layer in volcanically quiescent conditions.

Sources of stratospheric sulfur were the topic in the second session on Tuesday. The invited talk by **Michael Höpfner** presented an overview of the latest SO_2, H_2SO_4, and carbonyl sulfide (OCS) measurements from MIPAS Envisat (2002-2012), which can be used to derive a combined stratospheric sulfur burden estimate. **Simon Carn** ntroduced a new database of tropospheric volcanic sulfur dioxide emissions including 90-100 volcanic sources that have been quantified from OMI UV observations. A study using airborne and ship-based measurements together with transport model was presented by **Kirstin Krüger**. The results indicate that the tropical West Indian Ocean is a significant source of dimethyl sulfide and, possibliy, also of sulfur for the stratosphere. **Sinikka Lennartz** pointed out the severe discrepancies of 500-800 Gg S/year, between bottom-up and top-down ocean emission estimates of the tropospheric OCS budget, with the oceans (direct and indirect emissions) unlikely to explain the discrepancies. Details about how SO_2 measurements from near real-time volcanic plumes can be included in the ECMWF data assimilation system were provided by **Zak Kipling**.

Tuesday's keynote lecture by **Marc von Hobe** asked: "Do we understand the sources of stratospheric sulfur?". While the variability of stratospheric aerosol is mainly governed by volcanoes, there is a significant non-volcanic background, to which the largest contributor is OCS. However, significant gaps remain in our understanding of the tropospheric cycling of OCS. The contribution of anthropogenic SO_2 to the stratospheric aerosol layer is hampered by deficiencies in the understanding of scavenging in convection and further aerosol processing in the Tropical Tropopause Layer (TTL) and Asian Summer Monsoon anticyclone.

On day 3 the conference attendees made a field trip above the clouds to the Mt Teide volcano and the Izaña Atmospheric Research Station (IARC). IARC operates an extensive collection of in situ and remote sensing instrument and contributes to the WMO Global Atmosphere Watch (GAW) system with the high altitude Izaña Atmospheric Observatory (IZO). IZO is also an observing site for the Network for the Detection of Atmospheric Composition Change (NDACC). **Emilio Cuevas-Agullo**, director of IZO and local host of the AGU Chapman Conference, introduced the current activities at IZO and reviewed its contributions from over 100 years of observations.

Figure 8: *Instruments on the roof of the Izaña Atmospheric Observatory with Mt Teide in the background. (Photo: Stefanie Kremser)*

After his talk the participants visited the labs and the measurement platform on the roof of the observatory (Figure 8), where IARC scientists answered numerous questions.

Stratospheric aerosol climatologies were the focus of the first session on Thursday was. The invited talk by **Thomas Peter** presented the basis for the development of the CMIP6 Stratospheric Aerosol Record. The difficulties of using satellite optical measurements to infer aerosol physical properties and the potential of coupling in situ and satellite measurements to refine the satellite estimates was reviewed by **Larry Thomason**. **Sabine Griessbach** transferred the particle measurement techniques for Envisat MIPAS to a potential infrared limb sounding instrument and compared the measurement capabilities to established instruments (e.g. SAGE II, CALIOP, OSIRIS, GOMOS) indicating that global information on a daily basis is possible from a new infrared sounding instrument. A climate model study of investigating how well different aerosol climatologies simulate the post-Pinatubo eruption period was presented by **Laura Revell**. The difficulties of inferring aerosol properties from space-based measurements concentrating on limb scattering from instruments such as OMPS was also topic of **Pawan K. Bhartia**'s talk.

The focus of the second session on Thursday was on the climate forcing of stratospheric aerosol. **Mike Mills** and **Anja Schmidt**'s invited talk showed that small-to-moderate volcanic eruptions are a relevant climate forcing mechanism and can affect polar ozone depletion. **Jennifer Schallock** presented EMAC simulations of the climate response to stratospheric aerosol from volcanic eruptions. Based on model simulations, **Sergey Osipov** showed that SO_2 and ash from volcanic eruptions decrease photolysis rates, slow down SO_2 oxidation, and improve the agreement between simulated and observed sulfate aerosol optical depth. Combining global aerosol simulation and statistical methods (statistical emulation), was introduced by **Lauren Marshall** to predict the radiative impact of volcanic eruptions based on latitude and injection height of SO_2 emissions. **Valentia Aquila** showed, based on climate model simulations, that sulfate is not necessarily the dominant aerosol species in the UTLS during periods of low volcanic activity.

In Thursday's keynote lecture, "Stratospheric science and the cold war", **Matthias Dörries** took us back to initial stratospheric measurements and their rationale. He presented an overview of the work of several scientists, who investigated possible environmental consequences of atmospheric nuclear explosions. Between 1958 and 1962, the stratosphere became the site of explosions during the nuclear testing programs in which possible effects on Earth as well as on satellites were studied.

The first session on the final day of the conference was focussed on the climate response of stratospheric aerosol. **Ben Santer**'s invited talk reviewed research to identify the climate signals associated with a succession of moderate early 21^{st} century volcanic eruptions and concluded that multivariable climate signals of late 20^{th} and early 21^{st} century volcanic activity are statistically identifiable in observations, including signals from El Chichón, Pinatubo, and the post-2005 period.

Evgeniya Predybaylo investigated the radiative forcing and climate responses using climate models with prescribed volcanic aerosol datasets (CCMI, CMIP6, and SATO), and others, where volcanic aerosols are interactively calculated. Shortwave forcing as found mostly sensitive to the total optical depth and single scattering albedo, and to a lesser extent to the vertical structure of the volcanic aerosols. Another model study by **Susanne Bauer** investigated the role of interactive volcanic emissions on chemistry and climate, addressing the key question of whether volcanic forcings were represented very differently within the CMIP5 and CMIP6 framework, by going from non-interactive to interactive representations. A study showing that the observed pattern of decadal circulation change over the past decades is substantially driven by volcanic aerosol injections, consistent with numerical global atmosphere-chemistry model EMAC (ECHAM/MESSy Atmospheric Chemistry) in the lower stratosphere was presented by **Mohamadou Diallo**. The last talk of the morning session was given by **Brian Zambri**, who discussed the origin of Little Ice Age-like anomalies, demonstrating that nonlinear interactions are necessary to explain trends observed in the fully coupled system and discussing physical mechanisms through which these external forcings can trigger multidecadal modes of the Atlantic Multidecadal Oscillation inducing a Little-Ice-Age-like regime.

The final session of the Chapman Conference dealt withstratospheric aerosol and future climate. In his invited talk, **Brian Toon** discussed the impact of future climate change on stratospheric aerosol. Instead of making predictions he sketched a wide range of environmental changes impacting stratospheric aerosols, likely by the end of the century in a rational world. **Thomas Aubry** investigated the importance of eruption plume height on volcanic forcing, the implications for more realistic forcing reconstructions for future climate projections, and made projections about how a changing thermal structure of the atmosphere (mostly the tropopause) would impact the altitude of historic volcanic events. The potential climate effects of an Agung-like eruption in boreal autumn 2017, highlighting the importance of the background climate state for the prediction of future volcanic impacts on the regional and seasonal scale were discussed by **Claudia Timmreck**. Data from a new generation of balloon borne optical particle and condensation nuclei counters, developed at LASP/ University of Colorado based on the University of Wyoming heritage, was introduced by **Lars Kalnajs**. He showed that immediately following a volcanic event, balloons provide the only in situ measurement option, with the possibility of responding to an eruption within 6 weeks or less. **Joshua Kennedy** presented ice core evidence of recent volcanic eruptions and found a much stronger signal preserved from moderate high latitude eruptions compared to tropical eruptions, although the sampling location is a critical factor and needs to be considered for the interpretation of volcanic signals in ice.

In the final keynote, "Shedding Light on Earth's Volcanic Past Using Arrays of Ice Cores: How Common is Present-Day Volcanic Activity in a Multi-Millennial Context?", **Michael Sigl** impressively illustrated the long process from the drilling of an ice core, through the high-resolution measurements of the sulfate signal in ice, to the compilation of an ice-core based chronology of past volcanism.

Reports from the rapporteurs summarizing each session highlighting the open questions lead to lively discussions which occupied the rest of the day.

All presentations can be found on the SSiRC website: **http://www.sparc-ssirc.org/**

Figure 9: *Group picture of the Chapman Conference attendees.* *(Photo: Lauren Lipuma)*

Acknowledgements

We thank AGU for logistical and meeting support, Emilio Cuevas-Agullo for acting as our local host in Tenerife and organizing the tour of the Izaña Atmospheric Research Station, Hotel Botanico for providing excellent meeting, housing, and dining facilities, and the US-NSF, US-NASA, WCRP/SPARC, AGU, SSAI and LASP for supporting travel for the attendance of students and early career scientists.

Early Career Researchers Side Meeting at the Chapman Conference

Landon Rieger[1] and Stefanie Kremser[2]

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[2]Bodeker Scientific, New Zealand, (**stefanie@bodekerscientific.com**)

Dates:
19 March 2018

Organisers:
Landon Rieger (Canada)
Stefanie Kremser (New Zealand)

Meeting venue:
Hotel Botanico, Puerto de la Cruz, Tenerife, Canary Islands, Spain

Number Of Participants: 25

Sponsors:

Workshop Website:
chapman.agu.org/stratospheric-aerosol/

To bring together PhD students and recent graduates (<10 years), an informal Early Career Researchers (ECRs) meeting was held at the AGU Chapman Conference on *Stratospheric Aerosol in the post-Pinatubo Era* in Puerto de Cruz, Tenerife, Spain. In addition to meeting fellow ECRs, the goal behind the event was to provide ECRs with insight on how to talk to the media about climate change and scientific topics, including advice on the kinds of interactions scientists can expect and how to connect with the audience. With the growing interest in climate change and the influence of social media in driving the discussion, it is becoming increasingly important for scientists to know how to interact with media and the public in a scientifically literate, but also understandable and respectful way. To facilitate the discussion, **Ben Santer** first gave a slide-free talk on "How to interact with the media about climate change", incorporating stories and advice from his career, ranging from personal interactions to testimony before the U.S. Congress. This was followed by questions from the ECRs, initiating a lively conversation between Ben and the ECRs.

After the talk by Ben Santer and Q/A, an activity was organized where the ECRs split into two groups, and each given a hypothetical question that might be asked of a scientist by the media. They were given about ten minutes to formulate a reply to give to the three mock journalists, played by **Ben Santer**, **Marc von Hobe**, and **Thomas Peter**. One group had to prepare a reply regarding the Montreal Protocol while the other group was questioned about the role and importance of the IPCC. The ECRs had to focus on having a respectful discussion, with facts being in the foreground and not personal opinions or ideas. The journalists pressed the ECRs on their replies with follow up questions and a lively debate to prompt the ECRs to reduce their use of scientific jargon and focus on points of broad scientific consensus.

Figure 10: *Early career researchers being grilled by "journalists" Marc von Hobe, Thomas Peter, and Ben Santer at the Chapman Conference on Stratospheric Aerosol in the post-Pinatubo Era: Processes, Interactions and Importance, 19 March 2018.*

The event was not a traditional ECR event. Its informal nature, as well as the role-play were positively received by the ECRs. In a light atmosphere, they got an insight on what it might be like when questioned by the media and that it might be harder than expected.

Acknowledgements:

We would like to thank WMO and SPARC for funding the ECR side event and Yurena Gutiérrez from Hotel Botanico for helping in organizing the event at the Hotel Botanico. We would like to thank our 'journalists' Marc von Hobe, Thomas Peter and Ben Santer for providing their time to participate in that event.

The SPARC Capacity Development Intitiative

Fiona Tummon[1], Seok-Woo Son[2], Thando Ndarana[3]

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Capacity development has been a focus of SPARC since its very inception. This has included support of attendance of early career researchers and scientists from developing countries to SPARC-related workshops and meetings, organization of training activities, or provision of data. It has been more formally developed over the past few years, as the importance of capacity development has been realised. A focused side-meeting at the SPARC General Assembly in Queenstown, New Zealand, in 2014 brought the discussion to the fore. One of the outcomes of the meeting was a clear indication of the need for a greater emphasis on capacity development in SPARC. To assess the SPARC-related regional research activities and find out where expertise is lacking, a survey was conducted among the participants of the 2008 and 2014 General Assemblies.

Figure 11: *Participants of the 2nd ACAM training school: 'Observations and Modeling of Atmospheric Chemistry and Aerosols in the Asian Monsoon', Guangzhou, China, 10-12 June 2017.*

This in turn led to a dedicated two-day capacity development workshop being held in connection with the SPARC scientific steering group (SSG) meeting in Granada, Spain, in January 2015. It brought together a dozen representatives from different regions and international organisations who were identified, in part, through the survey, to further refine SPARC's strategy for capacity development. The main outcome of this workshop was SPARC's capacity development strategy (**www.sparc-climate.org/fileadmin/customer/6_Publications/ProgPlan_PDF/SPARC_CDstrategy_final.pdf**). The goals of this strategy are in line with the WCRP's own capacity development efforts, and directly reflect SPARC's need to maintain and extend education and capacity development activities to ensure continued excellence in its scientific research and leadership.

The goal of SPARC's capacity development activities has always been to ensure that scientific knowledge, methodological skills, and modelling expertise are developed in the regional and international SPARC community. SPARC research has followed a natural evolution moving from tackling global issues towards regional problems, reflecting a more general evolution of climate science as a whole. Understanding regional impacts and implications of climate change inherently requires regional knowledge and participation. Building capacity in all regions, particularly those most exposed to climate change, is thus a vital element to ensuring SPARC's continued contribution to policy-relevant sciences.

The progression of SPARC science towards a focus more on regional climate processes presents a new opportunity for capacity development. Previously unrepresented communities can more easily engage with SPARC science through regional activities.

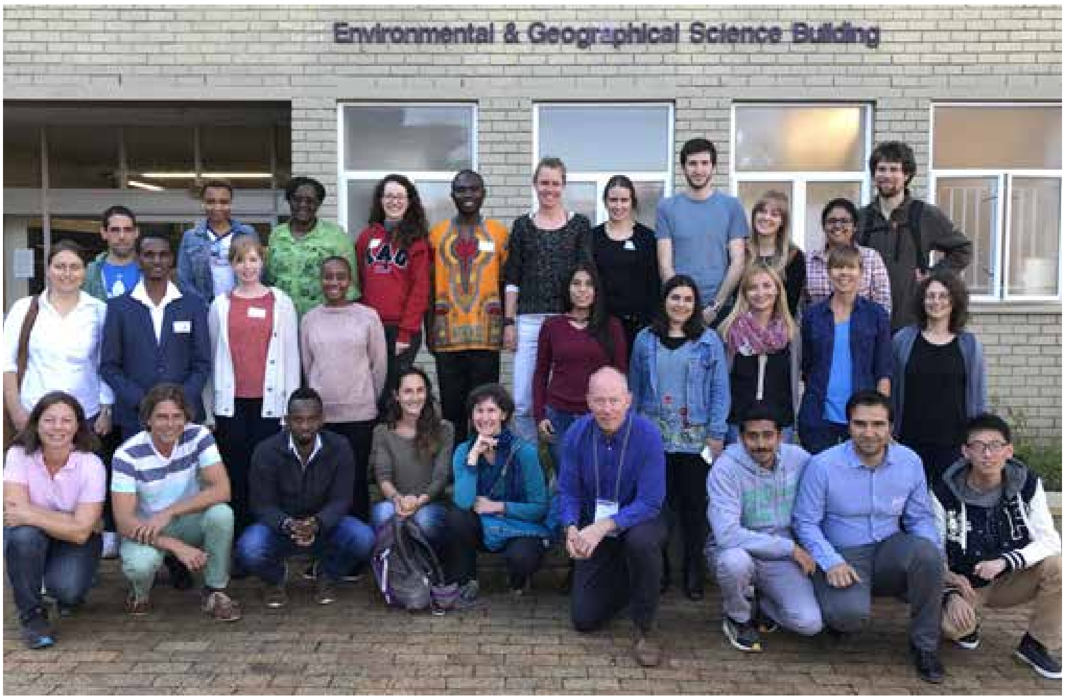

Figure 12: *IUGG training school: 'Stratosphere-Troposphere Interactions', Cape Town, South Africa, 2-5 September 2017.*

These regional activities aim to address regionally relevant issues, but within the larger global context of SPARC science. In this respect, several of SPARC's recent capacity development activities have done exactly this. Several training schools have been organised either as part of SPARC activities or as stand-alone events, however, often in conjunction with a larger conference or workshop. Recent examples include an Early Career Researchers Symposium held in Incheon, South Korea, in connection with the 2017 SPARC SSG meeting; a Stratosphere-Troposphere Interactions training school organised in Cape Town, South Africa, in September 2017; and the 2nd ACAM training school held in Guangzhou, China, in June 2017, among others. Further activities include the establishment of a regional SPARC working group in Asia, as well as strong links with the Young Earth System Scientists (YESS) community.

Figure 13: *ECR event during the Local workshop 'WCRP grand challenges and regional climate change', Incheon, Rep. of Korea, 18-20 October 2017.*

In order for SPARC capacity development efforts to succeed, a number of elements need to be in place. These include representation from all regions, including developing regions, on the SPARC SSG and in SPARC activities; a group of people within SPARC dedicated to capacity development issues (ideally including one SSG member); and a dedicated (at least 1 hour) slot at SPARC SSG meeting where capacity development achievements to date are reviewed and where plans for the future are discussed. To date, there has been a vibrant group of active SPARC members who have volunteered their time and energy to organising a wide variety of capacity development activities around the globe. The benefits of these initiatives will be seen for many years to come as careers develop and more regional balance is achieved. May these sorts of activities continue and grow further in future!

SPARC well represented at climate conference in Germany

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In collaboration with the United Nations Office of Outer Space Affairs (UNOOSA), the German Aerospace Center (DLR) organized a compact Conference on Climate Change (CCC2018), for the second time after 2016. It took place in Cologne, Germany, from 17 to 19 April. **Hansjörg Dittus**, responsible for Space Research and Technology on DLR's executive board, had initiated the series and opened this year's realization.

Under the title *Atmospheric research for understanding and mitigating climate change*, the conference aimed at bringing together renowned scientists, space agencies and interested parties with United Nations entities such as UNOOSA, UNSPIDER, UNFCCC, WMO and GCOS in order to provide a discussion forum to elaborate on the substantial challenges faced in atmospheric climate research. The intention was an open exchange of ideas to facilitate the implementation of suitable measures to support the requirements as outlined in the Paris agreement.

The opening session contained a number of programmatic contributions, among them a televised speech by **Petteri Taalas**, Secretary-General of WMO, about the role of WMO in the international climate agenda. The following four science sessions contained 30 invited overview presentations including three keynote lectures (cf. full programme under: **www.sparc-climate.org/ccc2018/**). **Thomas Stocker**, former co-chair of IPCC working group I, quantified the role of the world oceans for climate change and stressed the importance of continued ocean services. On the second day, **David Fahey** (SPARC SSG member during 2007-2013) thoroughly reviewed how the knowledge about the climate system improved, not the least by combining sophisticated airborne and space-borne measurements with model simulations and through international cooperation, *inter alia* maintained by WCRP and its core projects, among them SPARC. **Ottmar Edenhofer**, past co-chair of IPCC working group 3, lectured about the economic effects of climate change and argued that a complete phasing-out of coal combustion were both necessary and feasible.

Several colleagues, who are or were engaged in various SPARC activities, highlighted some of the many facets which are considered relevant for the current climate and envisaged trends. **Thomas Birner** (incoming co-lead of the FISAPS activity), introduced historically the circulation regimes of Hadley and Ferrel cells and presented simulation results indicating a future widening of the tropical belt with easterly winds. **William Collins**, who directs the emerging activity SLCFs, discussed the climate sensitivity due to short- lived air constituents termed "short-lived forcers" and introduced planned climate scenario calculations. **Bruce Anderson** reviewed the climatic impacts of aviation and reported results from joint American-German airborne campaigns, when the composition of exhausts from various fuel types was measured systematically.

In between the overview presentations, there was ample opportunity for discussion. Contributors included SPARC oriented colleagues of the DLR-Institut für Physik der Atmosphäre (IPA), as **Veronika Eyring** (chair, Coupled Model Intercomparison Project of WCRP), **Hans Schlager** (incoming co-chair, ACAM activity) and **Christiane Voigt** (OCTAV-UTLS emerging activity). Numerous scientists from research laboratories and university institutes in Germany and neighbouring countries presented their work on posters. **Hans Volkert** described the function of the SPARC-office which had started operations last January at its forth location in Oberpfaffenhofen, after 25 successful years in Paris, Toronto and Zurich.

Markus Rapp, director of DLR-IPA, concluded CCC2018 by summarizing highlights from the presentations. He regarded the event as a German contribution to international scientific cooperation following the agreement at COP-21 in Paris. The intended third CCC-realization in 2020 demonstrates continued concern and interest of the German space and climate research community.

Figure 14: *Snapshots from CCC2018 - DLR executive board member H. Dittus amidst contributors related to SPARC: Thomas Birner (FISAPS), Veronika Eyring (ESMVal), Markus Rapp (host of SPARC-office), Hansjörg Dittus (CCC initiator), Bruce Anderson (composition) and Christiane Voigt (OCTAV-UTLS), David Fahey (former SSG member; left to right). (Photos: Timm Bourry; collage: Hans Volkert)*

The SPARC newsletter welcomes historical notes. Background information about previous endeavours to obtain atmospheric data, to build comprehensive analyses, and to infer general characteristics can help to put current SPARC activities in perspective. Contributions and comments should be submitted to the SPARC International Project Office at **office@sparc-climate.org**.

Previous SPARC newsletter articles with historical topics include:

A. Brewer, 2000: The stratospheric circulation: A personal history. *SPARC Newsletter* No. **15**, 28-32.

M.-L. Chanin, 2004: A Short History of the Beginning of SPARC and its Early Development. *SPARC Newsletter* No. **22**, 10-12.

S. Brönnimann *et al.*, 2015: Bicentenary of the great Tambora Eruption. *SPARC Newsletter* No. **45**, 26-30.

James Sadler and the Discovery of the Stratospheric Quasi-biennial Oscillation

Kevin Hamilton

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Historical note

The observation and systematic description of the major features of the atmosphere's global-scale temperature and wind fields are a triumph of 20th century science. The first decades of the 20th century saw the development and widespread deployment of balloon platforms that were used to observe conditions up to the middle stratosphere. The remarkably swift winds characteristic of the core of the tropospheric jet stream were revealed in pilot balloon observations in the Northern Hemisphere extratropics as early as the 1920's (Lewis, 2003), and the jet-stream phenomenon was famously confirmed by widespread reports from military aircraft in WWII. By 1948 quite realistic temperature and wind cross-sections had been published showing the now familiar subtropical jet stream and its relation to the tropopause (Hess, 1948). In the high latitude stratosphere observations from the 1930's already showed the existence of a very cold winter polar vortex (see Krishnamurty, 1959). By 1955 the basic climatology of the stratospheric polar night jet and summertime easterly jet was established (Kochanski, 1955).

The nature of the prevailing winds in the tropical stratosphere was the last aspect of the zero-order global circulation to be understood, despite a very long history of related observations. The story of the discovery of the quasi-biennial oscillation (QBO) is fascinating and has been recounted at various levels of detail in textbooks (Craig, 1965; Newell et al., 1974; Labitzke and van Loon, 1999), personal memoirs (Lindzen, 1987; Reed, 2003; Wallace, 2015), comprehensive review articles covering tropical stratospheric dynamics (Wallace, 1973; Baldwin et al., 2001), as well as in specialised articles directly focused on the history of meteorological discoveries in the stratosphere (Maruyama, 1997; Hastenrath, 2006; Hamilton 2012). The present brief note points out a significant omission in all these earlier accounts and establishes the important contribution of James Sadler in the chain of discoveries that led to a correct understanding of the general circulation of the tropical stratosphere.

The story of the QBO discovery begins in the aftermath of the explosive eruption of Krakatau (the name is often rendered incorrectly as Krakatoa) in Indonesia on August 27, 1883. In the following months very spectacular twilight phenomena were observed over much of the world and scientists soon attributed the observed optical phenomena to the effect of aerosol from the eruption floating in the high atmosphere. Sereno Bishop, an amateur scientist in Honolulu, seems to have been the first to document the initial reports of the "Krakatoa sunsets" during the first days and weeks after the eruption. He concluded that the eruption had resulted in "a vast stream of smoke due west with great precision along a narrow equatorial belt with an enormous velocity, nearly around the globe" (Hamilton, 2012). His work was extended by Russell (1888) and established the presence of a strong (>30 m/s) equatorial easterly jet at heights we now know to correspond to the lower stratosphere.

The first hint that nature is more complicated occurred when the German meteorologist Arthur Berson made a series of pilot balloon observations of the winds in East Africa in 1908 and found evidence of westerly winds above 18 km altitude (Labitzke and van Loon, 1999). While there were some sporadic pilot balloon observations of the winds in the tropical lower stratosphere in the first half of the twentieth century (Hamilton, 1998), the record was sufficiently sparse for the conventional wisdom to have remained that the winds in the tropical stratosphere are predominantly strongly easterly ("Krakatoa easterlies") but that a narrow "thread" of westerlies ("Berson westerlies") is also sometimes present. In the early 1950's the US military began series of daily rawinsonde observations at various tropical Pacific islands in conjunction with several sets of atomic bomb tests they conducted in the Marshall Islands. Palmer (1954) examined some of the early rawinsonde observations from these locations, but interpreted these new data in line with the old Krakatoa easterly/Berson westerly paradigm.

As more direct wind observations near the equator became available it became clear that some fairly dramatic interannual variations must actually be occurring in the lower stratosphere. The relevant investigations seem to have proceeded independently in the US and the UK. At the UK Met Office the standard picture was challenged in a discussion held in December 1958 reported by Graystone (1959), who noted large and systematic interannual fluctuations of the zonal winds observed in the equatorial stratosphere. Following this, Ebdon and Veryard (1961) were then able to show that these variations took the form of nearly-repeatable cycles with a period near two years. These UK scientists deserve to be regarded as co-discoverers of what we now know as the QBO.

On the US side the QBO discovery is widely, and correctly, attributed to scientists at the University of Washington led by Richard Reed. Reed himself noted inspiration from some relevant preliminary work by F.E. McCreary:

"[Reed] and his colleague, Joost Businger, were present in September 1959, when Frank McCreary[...] presented a paper at an American Meteorological Society-sponsored meeting in Minneapolis, describing time variations in tropical stratospheric winds observed over the course of two years. The data showed an apparent downward propagation of successive easterly and westerly wind regimes. After perusing a summary of McCreary's presentation two months later in response to a suggestion by Businger, Reed concluded that the steady state paradigm for the tropical stratospheric circulation was no longer tenable and he began perusing the reports [from the US military] with tropical wind data that had been accumulating on the bookshelves in his office..." (from Wallace, 2015).

A native of Tennessee, James C. Sadler (1920-2005) was trained in meteorology at MIT and UCLA during and immediately after WW II. In 1957 he was a Major in the US Air Force (USAF) officially "on loan" to UH as part of a new effort funded by the USAF to support instruction and research in meteorology at the UH Manoa campus. Sadler remained at UH (joining as a full time faculty member in 1965) and went on to a distinguished career in tropical meteorology. He was a coauthor of the first paper to show very large-scale cloud patterns (including the ITCZ) photographed from space (in this case from a ballistic missile launched from Florida; Conover and Sadler, 1960) and he was later involved in identification and tracking of tropical cyclones using data from the earliest meteorological satellites. Sadler later became well known also for investigating the role of the "tropical upper troposphere trough" in synoptic development.

Reed reported on the results of his analysis and his view that there was a repeatable prevailing wind oscillation in his famous paper, Reed et al. (1961), that was submitted to J. Geophys. Res. in November 1960. McCreary was a United States Air Force (USAF) Colonel at the "Meteorological Center" (MC) for the Joint Task Force Seven (JTF7). JTF7 was the military organization that conducted the US nuclear weapons tests in the Pacific and McCreary was presumably involved in supervising the associated meteorological observations. The MC was located in Honolulu (first at the US Naval Base Pearl Harbor, later moving to the University of Hawaii [UH] campus).

I recently found that missing from this standard history is an earlier investigation by James Sadler which seems to have been the first to establish many of the key features of the interannual variation of the tropical stratospheric winds. McCreary (1961) himself refers to a paper "J.C. Sadler, Wind regimes of the troposphere and low stratosphere over the equatorial and sub-equatorial central Pacific. University of Hawaii publication, 1957". As far as I have been able to determine this (possibly informal) UH publication does not exist now, but there is a paper by Sadler with the identical title that was published in the proceedings of the 9th Pacific Science Congress, a meeting held in November 1957 in Thailand (Sadler, 1959). It seems reasonable to suppose that the information published by Sadler (1959) was in fact available to his Honolulu-based colleague McCreary as early as 1957 and likely provided McCreary inspiration to study the interannual variations in the tropical stratospheric wind.

For his 1957 conference paper Sadler examined vertical profiles of the horizontal wind from 9 Pacific island stations being run by the JTF7 within (154E-173E; 1S-20N), some with data as early as 1951. Many of these stations were only manned for short periods, so the records available to Sadler were somewhat fragmentary. Sadler showed that the day-to-day variations of the wind in the stratosphere were typically smaller than the interannual variations in the monthly-mean record. In several figures he documents the variation of the monthly-mean winds at different stations and periods, and finds striking interannual reversals. He had a continuous record from Majuro (7.1N, 171.4E) for at least February 1955 through July 1956 and he plots the winds each month, in most months up to 90,000 ft (27.5 km). He wrote:

> *"The Krakatoa easterlies were not present at 80,000 feet during 1955, but began to appear at this level in January 1956. From January through July the base of the easterlies lowered from 80,000 feet to 55,000 feet and the [peak] speed increased to greater than 60 knots during May, June and July. The variation of the lower stratospheric winds between the spring of 1955 and the spring of 1956 was rather amazing, changing from relatively strong westerlies to strong easterlies."*

Sadler's conclusions were:

- *"The equatorial [...] field of motion [...] has a large inter-annual variation but a remarkable intra-seasonal steadiness between transition zones"*
- *The lower stratospheric Berson westerlies are not always present. When present, they are not confined to a relatively narrow equatorial thread, but reach latitudes of at least 15 degrees in the Northern Hemisphere.*
- *The current generalizations of the equatorial field of motion [...] are [...] inadequate.*
- *Variations of such magnitude in the annual wind regimes of the equatorial region must play a large role in the general atmospheric circulation."*

The conference proceedings included transcripts of the question periods following the talks. The discussion for Sadler's paper has a question from the prominent tropical meteorologist Robert H. Simpson:

> *"Q: In view of the reversal of the stratospheric winds during this period, was any search made for anomalies in the circulations at higher latitudes in the Northern or Sothern Hemispheres which relate to the reversal or foreshadow it?; A: We have not done that yet".*

We see here already in 1957 the birth of the notion of QBO teleconnections!

By November 1957, Sadler had a complete and convincing critique of the standard model and an understanding of the data that brought him to the doorstep of the discovery of the QBO. His understanding in November 1957 was as sophisticated as the UK Met office discussion held over a year later (and that only considered wind data after October 1956). Unfortunately this seems to have been the only research that Sadler conducted dealing with the stratosphere in his long career and his role in the efforts that led to the "American" discovery of the QBO has been forgotten - until now.

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SPARC meetings

17 - 19 September 2018
LOTUS Workshop #2
WMO, Geneva, Switzerland

1 - 5 October 2018
6th SPARC General Assembly
Kyoto, Japan
www-mete.kugi.kyoto-u.ac.jp/SPARC_GA2018/index.html

6 - 8 October 2018
SPARC Scientific Steering Group meeting
Kyoto, Japan

6 - 8 November 2018
FISAPS Turbulence Workshop
IAP Kühlungsborn, Germany

7 - 9 November 2018
OCTAV-UTLS Meeting
Mainz, Germany

4 - 7 December 2018
2nd SPARC TUNER Meeting
IMK, KIT, Karlsruhe, Campus North, Germany

SPARC related meetings

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42nd COSPAR Scientific Assembly and Associated Events: "COSPAR 2018"
Pasadena, CA, USA

17 - 21 Sep. 2018
International workshops on subseasonal to decadal prediction
Boulder, CO, USA

25 - 29 September 2018
Joint 14th Quadrennial iCACGP Symposium/15th IGAC Science Conference 2018
Takamatsu, Japan

13 - 16 November
2018 WCRP Workshop: The Earth's Energy Imbalance and Its Implications (EEI)
Toulouse, France

10 - 14 December
AGU Fall Meeting
Washington D.C., USA

Find more meetings at: www.sparc-climate.org/meetings

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