SPARC
Stratosphere-troposphere Processes And their Role in Climate

newsletter n° 43
July 2014

www.sparc-climate.org

A team of NASA and University of Wyoming scientists has ventured into the Australian bush to send a series of balloons into the stratosphere to make measurements of a volcanic plume originating from neighboring Indonesia. Indonesia's Mt. Kelud exploded in February 2014, sending a plume of ash particles and sulfate aerosol up to 25 kilometres high into the Earth's stratosphere. The KlAsh (Kelud Ash) campaign, in Australia's Northern Territory, is part of SPARC's SSiRC activity and an effort to better understand the climate effects of volcanic eruptions. The campaign took place from 14-28 May 2014 (image courtesy: NASA).

Contents

SPARC going paperless

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Report on the 21st Session of the SPARC Scientific Steering Group 19-21 January 2014, Queenstown, New Zealand

Johannes Staehelin[1], Joan Alexander[2], Greg Bodeker[3], Fiona Tummon[1]

[1]SPARC International Project Office, Zurich, Switzerland, **johannes.staehelin@env.ethz.ch**, [2]Northwest Research Associates, Boulder (CO), USA, [3]Bodeker Scientific, Alexandra, New Zealand

The 21st Session of the SPARC Scientific Steering Group (SSG) took place in January 2014 in Queenstown, New Zealand, after the SPARC General Assembly.

Opening session and WCRP/ SPARC update

Greg Bodeker (SPARC co-chair) opened the meeting, particularly welcoming the new SSG members.

Toni Busalacchi (chairperson of the Joint Scientific Committee (JSC) of WCRP) then began his presentation by mentioning how impressed he was by the consistently high quality of the science presented at the SPARC General Assembly, as well as the sense of community, engagement with early career scientists, and, more generally, the SPARC leadership over the past few years. He discussed the outcome of the 34th JSC meeting (see SPARC Newsletter no. 42) as well as the WCRP Grand Challenges which provide new research foci and the basis for a new structure within WCRP, synthesizing input from across the four core projects. Over the past four years the WCRP sponsors (WMO, the Intergovernmental Oceanographic Commission (IOC), and the International Council for Science (ICSU)), have had major planning meetings to review their research programmes. They identified the need to be more agile in responding to user needs and to better support adaptation, mitigation, and risk management activities. From 2008-2010 the WCRP JSC deeply reflected on the outcomes of these meetings, developing several community white papers to better define WCRP's strategy to address these issues. The Grand Challenges will provide the main framework of this strategy, while the Working Group on Regional Climate (WGRC) will provide a vital interface with the Global Framework for Climate Services (GFCS).

Differences in terms of the implementation of the Grand Challenges exist and all projects have been asked to develop and articulate the implementation strategy for the Grand Challenge(s) they host/lead (SPARC's engagement in the Grand Challenges is further discussed below). The question was raised as to whether WCRP can influence the timing of the Intergovernmental Panel on Climate Change (IPCC) assessments, and whether WCRP should aim to produce synthesis papers prior to these assessments. Presently, the idea of a joint workshop between WCRP and the IPCC, similar to the workshop that took place after the 4th Assessment Report, is being discussed with Thomas Stocker, co-chair of IPCC Working Group I. Such a workshop would serve to evaluate the achievements of the 5th Assessment Report and to discuss emerging research topics that require more focus.

Future Earth presently has a 10-year time horizon (2015-2025). While the individual International Geosphere-Biosphere Programme (IGBP) projects will each sign a memorandum of understanding with Future Earth, WCRP as a whole will sign one memorandum of understanding. This reflects the fact that WCRP is more than just its core projects and is accountable to two sponsors besides ICSU, namely WMO and IOC. WCRP intends to continue relationships with the IGBP projects and develop further ties with new Future Earth initiatives as they arise. WMO will meet with ICSU to clarify the role of WCRP within Future Earth, particularly in terms of observational sciences, which currently do not seem to be well represented in the programme, and to ensure that physical climate research is continued.

Tony ended his presentation by discussing a new United Nations Environmental Programme activity called ProVia, officially sponsored by the World Meteorological Organisation (WMO), which is to fulfil a similar role to that played by WCRP for IPCC Working Group II.

Proposed SPARC activities

Hans Schlager presented a new activity focused on Atmospheric Chemistry and the Asian Summer Monsoon (ACAM; a joint activity with IGAC (International Global Atmospheric Chemistry)). The Monsoon affects regional air pollution through convective transport of surface emissions into the upper atmosphere and it is thought that this transport of aerosol and trace gases might lead to changes in cloud properties and in turn the entire hydrological cycle, as well as affecting the transport of air pollutants into the stratosphere. Their is particular concern about the possible effects of the rapid population and economic growth that has occurred in the Monsoon region and it's effects on regional atmospheric chemistry and dynamics. The coupling of emission source regions with topography and dynamics/meteorology is not well understood and experimental studies in this region are challenging. Improving collaborative efforts within the international community is thus essential, and the aim of ACAM is to form a new research community including as many regional scientists as possible. An ACAM side meeting was held at the 2012 IGAC Science Conference, which was then followed by the first ACAM workshop held in Kathmandu, Nepal, from 9-12 June 2013, where a majority of participating scientists came from the region. Since this workshop, activities have started in earnest, with the aim of attracting as many scientists from the region as possible. Further workshops will be held on an annual/biannual basis with some specifically aimed at training young scientists. ACAM also plans to promote data sharing and to help develop field campaigns in collaboration with local scientists. IGAC and SPARC have approved ACAM as an emerging activity, while the group develops their goals and structure. Michelle Santee will act as official SPARC liaison to the activity.

Marv Geller proposed a new SPARC activity focusing on the use of high-resolution radiosonde data to analyse fine-scale atmospheric structure. During a workshop that took place at Stony Brook University, New York, USA, in May 2013, discussions covered how these observations may be collected in future as well as research using these data. Several articles, for example in EOS and SPARC newsletter no. 42, have been published about the many uses of high-resolution radiosonde data. The National Oceanic and Atmospheric Administration (NOAA) will make all US high-resolution radiosonde data freely available (with a 1-2 month lag) and it was highlighted that it would be valuable if other countries could follow suite. While data from Indian radiosondes have been obtained free of charge for the 2004-2013 period, data from 1951 exist but will not be made available cost-free. The British Atmospheric Data Centre (BADC) has access to high-resolution radiosonde data from the UK and can likely also make these data available soon. For promotion to an emerging activity, the SPARC SSG has asked for a more refined proposal, including scientific goals, links to other activities such as GRUAN (GCOS Reference Upper Air Network) or GEWEX (Global Energy and Water Exchanges Project; another WCRP core project), as well as possible capacity development activities.

Emerging SPARC activities

Ed Gerber presented the status of S-RIP (SPARC Reanalysis Intercomparison Project). The activity's implementation plan was discussed, as well as the outline of the final report in which about 100 scientists will be engaged. A link to the data from the nine reanalyses to be investigated can be found on the S-RIP website (**http://s-rip.ees.hokudai.ac.jp/resources/data.html**). These data are on a common grid and available from the BADC. There are also plans to provide user-friendly online analysis tools. S-RIP was approved as a full SPARC activity.

Greg Roff presented progress made by SNAP (Stratospheric Network for the Assessment of Predictability). The goals of SNAP are related to stratospheric predictability and the activity aims to answer the following questions: (1) Are stratosphere-troposphere coupling effects important throughout winter or only when major stratospheric dynamical events occur? (2) How far in advance can major stratospheric dynamical events be predicted to add skill to tropospheric forecasts? (3) Which stratospheric processes (resolved and unresolved) need to be captured by models to gain optimal stratospheric predictability? For example, sudden stratospheric warmings (SSWs) can be very accurately predicted five days in advance, ten-day predictions prove to be reasonable, while 15-day predictions aren't yet useful for correctly predicting the evolution of the atmosphere and SSWs. Tropospheric predictability is not as good as in the stratosphere and there is potential to make improvements. Ensemble simulations from six or more models will be studied in this activity, therefore providing a comprehensive statistical analysis. All data will be placed on a common grid and made available at the BADC. While both activity co-leaders (Andrew Charlton-Perez and Om Tripathi) are funded until the end of 2015, the activity may not need to come to an end at this time and SPARC would like to have an additional co-leader to possibly provide some overlap. S2S (Sub-seasonal to Seasonal Prediction project; a joint activity between WCRP and the World Weather Research Programme) is very interested in results from the SNAP activity because at the moment S2S has relatively little expertise in the stratosphere. While the activity was accepted as a full SPARC activity, some thought is needed as to how the activity should evolve after 2015.

Full SPARC activities

The meeting continued in the same format that was introduced at the 20th SSG meeting, such that the activity leaders provided a short written report in advance of the meeting that included main scientific achievements of the past year, as well as an outlook and financial request for travel support for meetings to be held in the coming year. These reports, distributed among all participants prior to the meeting, were the basis for the discussion of the activities at the meeting.

Michaela Hegglin (new activity co-leader) reported on CCMI (Chemistry Climate Modelling Initiative; a joint activity between IGAC and SPARC). In addition to many modelling groups running simulations for the activity, they are also working on improving the diagnostic tool developed for the SPARC CCMVal-2 activity. This tool, now called the ESM (Earth System Model) diagnostic tool, is being developed with more focus on climate diagnostics, to be used for instantaneous model validation of both CCMI and any future CMIPs (Coupled Model Intercomparison Project). The aim is to run this tool online on the ESGF (Earth System Grid Federation; an open source effort providing a robust data and computation platform, enabling world wide access to scientific data). For collaboration between CCMI and AeroCom (Aerosol comparison between Observations and Models), see below.

Michaela continued by reporting on the SPARC Data Initiative, whose final report will be completed in 2014, when the activity will also come to an end.

Johannes Staehelin reported that SI2N (SPARC, IO3C, IGACO-O3 (Integrated Global Atmospheric Chemistry Observations), and NDACC (Network for Detection of Atmospheric Composition Change)) will also finish by the end of 2014. The SI2N special issue jointly organised between Atmospheric Chemistry and Physics, Atmospheric Measurement Techniques, and Earth System Science Data will remain open for submissions until September 2014. The possibility of a workshop focused on the upper troposphere/lower stratosphere (UTLS) was discussed, since many open questions about this region of the atmosphere remain. The workshop could potentially be organised between IGACO-O3, NDACC, GAW, and the SPARC SI2N, Data Initiative, and WAVAS-II activities since none of these activities have comprehensively looked at data quality and trends in the UTLS region to date.

SOLARIS-HEPPA (SOLARIS: Solar Influences for SPARC, HEPPA: High Energy Particle Precipitation in the Atmosphere), represented by **Bernd Funke**, organised a special session at the European Geophysical Union's 2014 meeting and the 5th International HEPPA meeting, which will took place in Karlsruhe, Germany, shortly thereafter in May. In addition to what is already planned within CCMI, SOLARIS-HEPPA will carry out detailed co-ordinated analyses of solar forcing within the CCMI simulations. And, also in collaboration with SCOSTEP (Scientific Committee on Solar-Terrestrial Physics), who have a sub-project studying the uncertainty associated with solar forcing more generally. Furthermore, SOLARIS-HEPPA will also provide solar forcing data for CMIP6 - both for the past and the future (with several future scenarios likely being produced).

DynVar (Dynamical Variability) was represented by **Elisa Manzini**, who reported that Ed Gerber had been selected as a new co-leader. DynVar has proposed that several diagnostics be included in CMIP6 so that features such as gravity waves can be properly assessed and compared. A new SPARC activity, the Quasi-Biennial Oscillation Initiative (QBOi) was proposed at the last SSG meeting (see SPARC Newsletter no. 41), however, at the moment this is being developed within DynVar.

Dian Seidel, representing the Stratospheric Temperature Trends activity, discussed some recent advances that the activity has made, including the fact that the UK Met Office has released a technical note about their Stratospheric Sounding Unit temperature dataset and the possibility of using the radio occultation dataset as a reference dataset, particularly in the UTLS where these data are of very high quality. Another question that was raised was whether stratospheric temperature data should be included in Obs4MIPs (an archive of observations for assessment of climate model output).

Karen Rosenlof indicated that WAVAS-II (Water Vapour Assessment II) will make its upper tropospheric water vapour data sets available to GEWEX as well as to the wider community through the SPARC Data Center (as was done for WAVAS-I). The activity will finish by the middle of 2015.

Quentin Errera will become the new leader of the Data Assimilation activity, while **Kaoru Sato** will join **Joan Alexander** as co-leader of the Gravity Waves activity.

With the publication of its final assessment report (see **http://www.sparc-climate.org/publications/sparc-reports/sparc-report-no6/**), the Lifetimes of Halogenated Source Gases activity has come to an end.

Markus Rex reported that the first scientific workshop of SSiRC (Stratospheric Sulfur and its Role in Climate), held in Atlanty, Georgia, USA, in October 2013 was very successful (see further details in a separate article on page 25).

WCRP Advisory Councils

Kaoru Sato presented an update on the WDAC (WCRP Data Advisory Council). An important priority for WDAC is the Essential Climate Variable inventories that are vital to the Global Observing System Information Centre and wider community as a whole. The Committee on Earth Observation Satellites (CEOS) is producing ECV's following GCOS (Global Climate Observing System) data guidelines and monitoring principles. There was some discussion as to whether WDAC would need to form a task team to deal specifically with reanalyses, however, for the moment a dedicated website (**reanalysis.org**) has been established. Surface flux data is a key gap within WCRP and it was recommended that WDAC lead a new effort to solve this problem. Finally, there was also some discussion related to the quality of data going into Obs4MIPs.

Joan Alexander then continued by reporting on WMAC (WCRP Model Advisory Council), which to date has held two meetings. WMAC endorsed the ESGF as the main mechanism to be used for data exchange. It was also highlighted that although the CMIP6 timeline is very demanding it is essential that a strategy for significant model development and improvement be devised. To this end, WMAC has encouraged the establishment of several prizes and summer schools to promote model development. The possibility of organising several workshops was also discussed. One idea was to focus on model parameter sensitivity (or model tuning), a subject about which data assimilation may be able shed some light. Another idea was to have a combined workshop focused on dynamics-physics coupling in models, since different communities usually address physical parameterizations and dynamics separately.

In terms of SPARC activities, WDAC encouraged the Gravity Waves activity to liaise with the Working Group on Numerical Experimentation (WGNE) on surface drag analyses, and there was some discussion about the choice of scenarios for the reference CCMI simulations. WMAC also suggested that the CORDEX (Coordinated Regional Downscaling Experiment) model error evaluation framework be reconsidered.

SPARC contributions to the WCRP Grand Challenges

SPARC will contribute to the Grand Challenge on 'Clouds, Circulation, and Climate Sensitivity' in two ways. This Grand Challenge aims to reduce climate sensitivity uncertainty, which is thought to stem largely from the way in which models represent clouds. A recent analysis by Bony *et al.* (2013) showed that circulation biases (dynamics) are crucial, not just changes expected from thermodynamics. **Ted Shepherd** reported that the entire range of models will be needed to improve our understanding of clouds and circulation patterns. This Grand Challenge cuts across the WCRP community and includes five initiatives (see **http://www.wcrp-climate.org/documents/GC4_Clouds_14nov2012.pdf**). SPARC will take a leading role in the 'Changing Patterns Initiative', which has several foci. The further planning of this and the other initiatives was discussed at a small kick-off workshop that took place in late March 2014 in Ringsberg, Germany.

SPARC will further contribute to this Grand Challenge through the work of CCMI and AeroCom, looking at aerosol forcing and its effect on cloud and circulation changes. AeroCom and CCMI will work together under the umbrella of the AerChemMIP of CMIP6. For this, Climate Model Output Rewriter (CMOR) tables will need to be provided to CMIP6; a matter that was discussed at the CCMI workshop held in Lancaster, UK, in May 2014.

To further address the matter of systematic model bias related to atmospheric modes of dynamical variability, **Mark Baldwin** proposed that a workshop be organised in Grindelwald, Switzerland, in September/October 2015. This workshop would be similar to the SPARC Brewer-Dobson Circulation Workshop held in 2012, but would aim to include the wider WCRP community (CLIVAR, CliC, GEWEX, and WGSIP). Possible funding sources included SPARC and national science foundations. **Dian Seidel** discussed a workshop on "The Width of the Tropics: Climate Variations and Their Impacts", she proposed organising as an American Geophysical Union (AGU) Chapman conference to take place in summer 2015.

SPARC will contribute to the Grand Challenge on 'Cryosphere in a Changing Climate' through the Polar Climate Predictability Initiative (PCPI). **Cecilia Bitz** and **Ted Shepherd** made a presentation mentioning that the disagreement between models and observations is substantial and opposite at the two poles, and that the polar regions may contain sources of predictability on both seasonal and decadal time scales. For PCPI, which consists of 6 activities each headed by two co-leaders, the global reach of WCRP is very important. The activities are mostly still in the planning stage, although one group organised a session at the Fall 2013 AGU meeting and a pan-PCPI workshop of leaders and other key people took place in Boulder, Colorado, USA from 3-4 April 2014.

Finally, SPARC will also contribute to the Grand Challenge on 'Regional Climate Information' through the work of DynVar and SOLARIS-HEPPA.

Feedback about 5th the SPARC General Assembly

Veronika Eyring and **Adam Scaife** presented feedback about the SPARC General Assembly from the Scientific Organising Committee. The conference programme, one-minute poster presentations, and the combination of overview and contributed talks were all very well received. It was suggested that it might be valuable to have poster clusters focusing on SPARC activities and possibly have the posters hanging for more than one day, with more time allocated to the poster sessions.

It was discussed whether an invited (45 minute) talk at the next General Assembly could be announced as a prize to honour scientific publications that solve key SPARC science questions, just as WMAC is setting up prizes for model development. Examples of questions important to SPARC include: (1) Is interactive chemistry necessary for surface climate prediction (that is, is a fully coupled atmosphere-ocean-chemistry model required)? (2) How much does UV irradiance vary across the solar cycle and what impact does this have on surface climate? (3) What is the role of the stratosphere in systematic model bias (*e.g.* errors in the stratospheric jet)? (4) Does a good representation of the stratosphere improve decadal prediction of surface climate? (5) What is the regional impact of stratospheric geoengineering? (6) What is the mechanism by which extra-tropical stratospheric circulation affects surface climate? (7) What is the role of the stratosphere in the surface temperature hiatus? (8) Do changes in the cryosphere impact the stratosphere-troposphere system? However, it was mentioned that it would be somewhat challenging to decide whether one paper answers a particular question or not, since the science behind any one question may have been built up by a large number of people. It was thought that the SSG could decide whether and to whom the prize would be awarded in a fair and justifiable way.

Presentations from other WCRP bodies

Detlev Stammer made a presentation about CLIVAR (Climate Variability and Predictability; a WCRP core project), which is presently going through a transition phase, including a change to their logo. CLIVAR now has three international project office nodes (in Italy, India, and China), as well as a US-CLIVAR project office, raising some challenges concerning optimal organisation. CLIVAR has several regional activities (ocean basin-wide) as well as a few global activities, one of which is focused on paleoclimate and another on how observations can be used to initialize climate forecasts on various time scales. CLIVAR also has several core panels and a regional sea-level rise activity that is under development. **Elisa Manzini**, who participated in the 2011 and 2013 CLIVAR SSG meetings, highlighted the benefits of a close collaboration between CLIVAR and SPARC, in particular with DynVar in terms of regional climate and decadal climate prediction.

Veronika Eyring reported on WGCM (the WCRP Working Group on Coupled Modelling) and CMIP, a sub-group of WGCM. The CMIP panel had their first CMIP6 planning meeting in Aspen, Colorado, USA, in August 2013. The CMIP6 experiment protocol will take the form of a core set of simulations called the CMIP DECK (Development, Evaluation, and Characterisation of Klima), with a large number of satellite MIPs (Model Intercomparison Projects) focusing on particular aspects of the climate system. The CMIP6 experimental design will be finalized at the next WGCM meeting in October 2014. Veronika noted that CMIP6 is aimed at supporting research going into the WCRP Grand Challenges, but that within the Grand Challenges there is very little focus on biogeochemistry. To fill this 'gap', CMIP6 will work closely with the IGBP AIMES project (Analysis, Integration, and Modelling of the Earth System), which will become part of Future Earth as of 2015. WGCM will also work closely with WGNE and all the MIPs, including CCMI, to develop climate metrics for model benchmarking and routine model evaluation. The CMIP6 historical forcing data sets will need to be ready within one year and SPARC will contribute to this through the provision of an ozone database (CCMI) and solar forcing (SOLARIS-HEPPA). DynVar will also contribute significantly to CMIP6 through, for example, providing some diagnostics required for model assessment.

WGSIP (WCRP Working Group on Seasonal to Interannual Prediction, presented by **Adam Scaife**) works closely with WMO Global Forecast Producing Centres, operational centres responsible for real-time weather forecasts. They have been working together on the Climate-system Historical Forecast Project (CHFP), an experimental framework for sub-seasonal to decadal predictions of the complete physical climate system. A series of hindcasts is now available in an online database (14-15 hindcasts, with seven models including a resolved stratosphere). Initial results show that the predictability of several extra-tropical features, such as the North Atlantic Oscillation (NAO), Arctic Oscillation, and Antarctic Oscillation, have improved significantly. Until very recently, seasonal forecasts of these oscillations did not have much skill, largely because of high internal variability. With recent model advances the NAO can now be predicted fairly well 1-4 months in advance, and the skill improves with more ensemble members. It is hoped that forecasts of extra-tropical regions will be as skilful as current tropical forecasts within a few years. WGSIP has also been investigating decadal prediction and found that proper initialization of ocean and surface air temperatures is important for predictability of the first five years simulated, while thereafter forecast skill is much lower. They have also been testing the feasibility and usefulness of initializing different components of the climate system, not only the ocean but also land surface or the stratosphere. No structure presently exists to provide real-time decadal forecasts, and the possibility of doing so is presently under investigation (*i.e.* providing such forecasts once per year, with several centres contributing to the effort). Further research is focused on exploring whether the operational use of satellite limb measurements could improve forecasts through data assimilation processes. At present these observations are not assimilated in real-time, and it remains uncertain as to whether many of these space-borne measurements will be continued.

Other presentations

Geir Braathen reported on GAW (Global Atmosphere Watch) and its activities of relevance to SPARC. GAW consists of several global stations and hundreds of regional stations which all produce key atmospheric measurements that are used to produce several WMO products, for example the WMO Aerosol and Antarctic Ozone bulletins. The MACC (Monitoring Atmospheric Composition and Climate) project was mentioned as possibly being of interest to SPARC. This project is assessing models using GAW and NDACC tropospheric ozone data and also aims to improve the dialogue between modellers and those making measurements in these networks. Of significant relevance to SPARC is the fact that the WMO would like to have a more defined standpoint on geoengineering. They will be organising a workshop dedicated to further developing this, to be held later in 2014. Scientists active in this field are invited to contact Geir for further information and the possibility of participating in the workshop. The workshop will also be relevant in the context of answering the question regarding which UN body should be responsible for the knowledge basis of geoengineering.

John Burrows presented an update on COSPAR (COmmittee on SPAce Research), which is made up of eight separate commissions, of which commission A (Space studies of Earth's surface, meteorology and climate) is most relevant to SPARC. He encouraged participation in the next COSPAR Assembly, taking place in Moscow, Russia, from 2-10 August 2014. COSPAR is currently involved in a review of the status of atmospheric observations from space in which they will make several recommendations regarding the development and continuation of these measurements. SPARC, in particular, could help define the consequences of *not* having certain observations since crisp and compelling scientific-based reasons are needed to justify the launch of new satellite missions at present. It is possible that climate-continuity missions from NASA may provide an avenue for the continuation of limb observations in future and there is some hope that Canada will have satellite missions replacing the OSIRIS and ACE-FTS instruments; international support for this would certainly be useful. It was also suggested that it would be important to exploit the International Space Station (ISS) as a useful observational platform.

Mike Kurylo started his presentation on NDACC by asking for input from SPARC and WCRP to assist in NDACC's development and reassessment of its measurement systems. In particular, it would be valuable to receive information regarding priorities and where potential solutions to existing problems may lie. A major issue for NDACC is the fact that agencies provide funding to make measurements, but not necessarily to put the data obtained into the right format for transferal to databases or for any further evaluation. Tropospheric ozone and water vapour observations are new foci for NDACC. As are aerosol sonde observations, which to date have largely been campaign-based in nature, but which could be very useful for satellite validation. NDACC is considering establishing these observations at a few selected NDACC sites. Finally, frost point hygrometers have recently been added to the NDACC network in cooperation with GRUAN. A large number of UV/visible spectrometers are no longer operating within NDACC and this is of considerable concern.

New SPARC Implementation Plan

Joan Alexander presented key input for the new SPARC Implementation Plan, focused on the 2015-2020 period. The previous plan dates to 2009. The new plan will address important changes both in SPARC and in WCRP as a whole. The new implementation plan will be based on the "Whole Atmosphere Approach" since many of the waves, modes, and transport mechanisms that communicate climate signals and teleconnections extend across or through traditional atmospheric layers such as the troposphere, stratosphere, and mesosphere.

The new implementation plan will be focused around three themes. Theme 1, 'Chemistry in climate', would aim to improve our understanding of the interactive role of atmospheric chemistry in the climate system. This demands both new and continuing observations along with chemistry-climate model development and validation.

Theme 2, 'Atmospheric circulation in climate', would include theoretical and observational studies of dynamics and atmospheric variability, underpinning the science of shifting regional circulation patterns and the likelihood of extreme events. At present, changes in atmospheric circulation patterns are a key uncertainty in climate prediction and this theme would aim to reduce this uncertainty.

Theme 3, 'Long-term records for climate', would cover activities concerned with creating, analysing, and interpreting climate data records created from ground- and space-based observational records.

SPARC contribution to GFCS

In 2009 the **3rd** World Climate Conference established a high level task force on GFCS, which produced a report in 2011. An extraordinary meeting of the WMO Congress led to the development of the Intergovernmental Board on Climate Services, which adopted the GFCS Implementation Plan and its annexes, as well as the Compendium of GFCS projects, which are to be funded through the GFCS Trust Fund. A main focus of GFCS is capacity development since more than 70 countries around the globe have little or no basic climate services. There is also a strong need to improve how information is provided to users and, to meet this requirement, a User Interface Platform is being established. SPARC's contribution to the GFCS needs to be developed. At present only WCRP's contributions have been clarified. WCRP was tasked with looking at the science required and the main gaps that need to be addressed within GFCS. This includes cooperation with the meteorological forecasting community to develop seamless weather-climate predictions. Nine out of the 40 activities proposed in the annex of the GFCS Compendium have so far been taken up in the final implementation plan, with some resources allocated. WCRP will also be involved with activities focused on improving regional systems for providing climate services. Current plans don't fully exploit how WCRP Grand Challenges can contribute to the GFCS plans, and this will need to be discussed in future.

SPARC Capacity Development

Thando Ndarana and **Carolin Arndt** reported on a short Capacity Development workshop that took place during the SPARC General Assembly. The workshop helped define the objectives of SPARC's Capacity Development activity, which are to:

- Develop tailor-made solutions for SPARC's involvement in different regions,
- Stimulate bottom-up initiatives,
- Help build lasting and

- sustainable hard/soft skills related to conducting SPARC-related research in each region,
- Build on existing networks and structures to facilitate the required learning environment.

The following actions were proposed for 2014: (1) a survey will be carried out to establish where scientists are involved and interested in SPARC activities, focusing on developing and emerging economies; (2) representatives from different regions will help collect information, particularly within the context of where SPARC research may fit into the regional research scene and in terms of what capacity development programmes/activities are already underway; (3) based on the information gathered, a two-day SPARC Capacity Development workshop is envisaged (possibly with around a dozen participants, to be identified at a later stage), with the aim of developing a firm plan for SPARC with a time horizon of around five years. It was suggested that researchers from developing countries provide as much information as possible, in particular, identifying the state of current SPARC research in their region (or lack thereof). This will help with preparations for the workshop and hopefully will provide a better idea of where gaps lie, what requirements there are, and where best we might place resources. The SPARC Capacity Development effort should benefit from SPARC science as well as improve regional science capacity. It will be important to ensure that solutions are not imposed, but rather that those involved have full ownership of the activity. To ensure this plan moves forward, possible funding mechanisms (within WMO and other institutions) will need to be identified.

Other SPARC items

The SPARC Project Office is presently funded until the end of 2015. **Thomas Peter** will submit formal proposals to the SPARC Office sponsors asking for an extension of funding to cover the 2016-2017 period.

Although a NASA proposal to continue support of the SPARC Data Center (SDC) for a further three years was turned down, NASA did provide some resources for **Peter Love** (SDC manager) and **Marv Geller** to visit the BADC to discuss the transfer of the SDC to the BADC. A memorandum of understanding has since been signed and the data transfer will be completed by the end of 2014. Peter Love is now working at the Australian Antarctic Division, with support to work about 10-20% of his time for the SDC for one year. Under the new system, a SDC scientist is not included, but a contact person at the BADC will be assigned. In turn, SPARC will need to nominate a liaison person who would answer any questions that come from BADC. Data access will be administered by the standard BADC rules and all submitted data will need to be in BADC format with proper documentation. Each SPARC activity will need to submit its data separately to the BADC, after having established a data management plan (a process that is designed to be simple and not very time consuming). Importantly, the UK Natural Environment Research Council is willing to act as a publisher of DOI's of all SPARC datasets. At present, a mirror (for faster access and backup) of the SDC exists, but this will likely no longer be necessary with the SDC hosted at BADC.

The first SPARC Annual Report was produced in 2013, with the aim of providing an overview of SPARC's activities and an avenue for following SPARC's evolution over time. Given the warm reception of the 2012 Annual Report by the WCRP JSC and its success in general, it was decided to continue with the production of the SPARC Annual Report (see **http://www.sparc-climate.org/publications/programme-plans/** for the 2013 SPARC Annual Report).

Greg Bodeker is no longer able to continue as SPARC co-chair, and **Joan Alexander** warmly thanked him for the enormous amount of time he dedicated to SPARC, including the preparation of the very successful General Assembly. As of February 2014 he has been 'outgoing co-chair', with **Ted Shepherd** as 'interim co-chair'. **Neil Harris** will join Joan as co-chair as of September 2014.

The next SSG Meeting will take place from 12-16 January 2015 in Granada, Spain.

Report on the 5th SPARC General Assembly
12-17 January 2014, Queenstown, New Zealand

Julie Arblaster[1,2], Veronika Eyring[3], David Fahey[4,5], Michelle Santee[6], Kaoru Sato[7], Adam Scaife[8], Paul Young[9], Simon Alexander[10], Chaim Garfinkel[11], Marvin Geller[12], Adrian MacDonald[13], Scott Osprey[14], and Susann Tegtmeier[15]

[1]Bureau of Meteorology, Melbourne, Australia, [2]National Center for Atmospheric Research, Boulder, USA, [3]Deutsches Zentrum für Luft- und Raumfahrt (DLR), Institut für Physik der Atmosphäre, Oberpfaffenhofen, Germany, [4]NOAA Earth Science Research Laboratory, Boulder, CO, USA, [5]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA, [6]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, [7]Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan, [8]Met Office Hadley Centre, Exeter, UK, [9]Lancaster Environment Centre, Lancaster University, Lancaster, UK, [10]Australian Antarctic Division, Kingston, Tasmania, Australia, [11]Institute of Earth Sciences, Hebrew University, Israel, [12]School of Marine and Atmospheric Sciences, Stony Brook University, New York, USA, [13]Centre for Atmospheric Research, University of Canterbury, Christchurch, New Zealand, [14]National Centre for Atmospheric Science, Department of Physics, University of Oxford, Oxford, UK, [15]GEOMAR Helmholtz Centre for Ocean Research, Kiel, Germany

Beautiful Queenstown, New Zealand, was host to the nearly 300 scientists from around the globe that came together to participate in the 5th SPARC General Assembly from 12-17 January 2014. Usually held every four years, the six-year gap since the last General Assembly in 2008 meant that a lot has happened since SPARC had its last 'family reunion' in Bologna, Italy. SPARC's evolution has continued and its reach has extended to include aspects of the troposphere which have links with the stratosphere. This expanded focus was well reflected in the choice of the assembly themes and the science presented during the conference.

SPARC General Assemblies provide a platform to share research results, scientific ideas, and our passion for what we do. General Assemblies are also opportunities for SPARC to take stock of what has been achieved, where gaps in SPARC's research portfolio lie, and to define which areas SPARC needs to be moving into in order to remain responsive to the needs of both its members and the users of SPARC research products. All oral presentations were held in plenary, *i.e.* without parallel sessions, and were divided into six themes, namely: 'Emerging and outstanding research of relevance to SPARC'; 'Atmospheric chemistry, aerosols, and climate'; 'Stratosphere-troposphere-ocean dynamics and predictability of regional climate'; 'Coupling to the mesosphere and upper atmosphere'; 'Observational datasets, reanalyses, and attribution studies'; and 'Tropical Processes'. Each of the latter five themes had a dedicated poster session and, as is SPARC tradition, particular emphasis was placed on these sessions since they provide an unparalleled opportunity for in-depth discussions and scientific exchange at all levels. As a novelty, 45 minutes were allocated for poster presenters to give a one-minute overview of the main highlights of their work. This solicited a great response with some very creative performances and was very well received by all.

Most of the oral presentations and all abstracts are available online and can be downloaded from: **http://www.sparc-climate.org/meetings/general-assembly-2014/#c1122**. A selection of photos taken during the assembly can be viewed on the same website. The following report is a summary of some of the highlights from each of the six themes.

Emerging and Outstanding Research of Relevance to SPARC

The opening session on Sunday 12 January focused on emerging and outstanding research of relevance to SPARC's new mandate encompassing stratospheric and related tropospheric processes of importance to climate science.

The General Assembly began with an opening lecture by **Jerry Meehl** who presented an overview of the projections and predictions in the IPCC 5th Assessment Report (AR5), highlighting progress since the **4th** Assessment Report (AR4). He emphasized that the models have improved with respect to their simulation capabilities. Of the more than 40 models that participated in CMIP5 (Coupled Model Intercomparison Project Phase 5), around 14 were 'high top'

Figure 1: Participants of the 5th SPARC General Assembly held in Queenstown, New Zealand.

models with a resolved stratosphere and several were Earth System Models (ESMs) including aerosols and interactive tropospheric and/or stratospheric chemistry. Time-varying stratospheric ozone was used, constituting a substantial improvement since AR4 where half of the models prescribed a constant climatology. As a result, AR5 concluded that there is robust evidence that the representation of climate forcing by stratospheric ozone has improved since AR4. Jerry finished his talk with an outlook on the CMIP6 (Coupled Model Intercomparison Project Phase 6) experimental design (Meehl *et al.*, 2014) that is open for discussion until September 2014. The specific experimental design would be focused on three broad scientific questions on (1) systematic biases; (2) response to forcings; and (3) variability, predictability, and future scenarios. With an invited talk on recent advances in understanding cloud feedbacks, **Steven Sherwood** linked to the new SPARC focus on including tropospheric processes. He showed that many aspects of the cloud response in GCMs are consequences of relatively well-understood changes in general circulation patterns, with the deepening of the troposphere and the poleward shift of storm tracks particularly of relevance to SPARC. Models still have problems in simulating low-cloud cover but he showed new results that offer a likely explanation for the observed inconsistency among models. He finished his talk by providing recommendations for how SPARC could contribute to help answering questions in this research area, highlighting in particular the role of dynamics, the stratosphere, and the Tropical Tropopause Layer (TTL) in cloud control and cirrus cloud feedbacks.

WCRP and WWRP have recently initiated research and prediction projects on polar climate. One of these, the Polar Climate Predictability Initiative is co-led by **Ted Shepherd**, who gave an invited talk on this topic. Ted pointed out that the polar amplification of climate change and rapid melting of Arctic sea-ice contrasts with the Antarctic where sea-ice has slowly increased in area. The maximum Arctic melting in autumn gives rise to a seasonality in the rate of change, with a corresponding maximum in Arctic warming rates. The consequences of this for coastal impacts, including ecosystems, are just beginning to be understood as impacts emerge. Arctic amplification of anthropogenic warming due to the albedo feedback and other effects has long been seen in climate models and gives rise to great consistency between models compared to changes in many other regions of the globe. However, there is still uncertainty, particularly around Antarctic changes, and Ted noted that the ozone hole and associated circulation changes may be involved in the hemispheric asymmetry in recent trends. He also noted that internal variability is high at the poles and that stratosphere-troposphere interaction is a key element of this variability, acting through the North Atlantic Oscillation/Arctic Oscillation and Southern Annular Mode (SAM). Some of these processes are well reproduced in models, for example, the response of surface climate to sudden stratospheric warmings is simulated in several models. This link may also be involved in prominent long-term variability of polar climate on decadal timescales and a few studies are now suggesting it has a role in climate change. Ted noted that ultimately, it is improvement in the Arctic process modelling such as in the Arctic boundary layer that will resolve current uncertainty and provide better predictions.

Continuing the theme of interaction between the SPARC community and tropospheric climate science, **Christian Jakob** gave his insights in an invited talk on 'Long Standing Errors in Climate Models'. After pointing out that both climate and weather predictions are based on the same core models, he presented the great progress made in improving accuracy of weather forecasts and the significant increase in complexity of climate models over recent decades. He also showed evidence that surface climate is reproduced with greater fidelity in the latest CMIP5 models compared to earlier generations of models. However, in stark contrast to these improvements, the hydrological aspects of models connected to cloud radiative properties in particular have shown little progress and still represent a great source of model spread. He highlighted a recent intercomparison of aqua planet simulations where even the response to warming was not qualitatively similar across models due to different mean model biases. All of this also projects onto atmospheric circulation and regional model biases. He advocated application-, phenomenon-, and process-based analyses of models to reduce model error and urged the community to put more effort into this important underpinning task.

Dian Seidel returned to the stratosphere, but with an eye on the troposphere, to discuss temperature trends in an invited talk. She gave a historical perspective of work over the last few decades, starting with seminal works using 1D models on the radiative-convective effects of increasing greenhouse gases and then continuing to demonstrate the importance of the radiosonde network in identifying sources of stratospheric temperature variability from the Quasi-biennial Oscillation (QBO), El Niño-Southern Oscillation (ENSO), and volcanoes, for example. Dian highlighted the uncertainties in trends from both sondes and satellite datasets and the difficulties of stitching together records from different instruments, including the recent uncertainty over satellite data processing methods, which is now being revisited. She also discussed other sources of observations and pointed out that reanalysis datasets are not necessarily the answer as they contain very different stratospheric temperature trends. Intriguingly, the expected cooling of the stratosphere is not linear in time and may even occur stepwise in relation to volcanic eruptions, however, all of this occurs on a background of complex instrument errors that are not stationary in time.

In the final invited talk of the day, **Robert Sausen** provided an overview of the impact of aviation on atmospheric composition and climate. He showed that the non-CO_2 climate effects from aviation are large in comparison to the CO_2 effect, in particular as a result of the triggering of new clouds or modification of existing clouds, as well as the emission of nitrogen oxides that produce tropospheric ozone and reduce methane. He also emphasized that emissions from aviation are increasing particularly fast, and faster than the sum of all anthropogenic impacts. Research is underway to study whether aviation impacts can be reduced by changing the location and time of emissions, *i.e.* by climate optimized flight trajectories.

Atmospheric Chemistry, Aerosols, and Climate

Atmospheric composition is an area where SPARC has been very active in its efforts to emphasize stratospheric links to the troposphere. Together with the International Global Atmospheric Chemistry (IGAC) programme, SPARC has sponsored both the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP) (Lamarque *et al.*, 2013) and, more recently, the Chemistry-Climate Model Initiative (CCMI) (Eyring *et al.*, 2013). The IGAC/SPARC CCMI is a merge of ACCMIP and the SPARC Chemistry-Climate Model Validation (CCMVal) activity, expanding the goals and deliverables of CCMVal to include tropospheric chemistry-climate. CCMI not only brings together the tropospheric and stratospheric modelling communities, but also entrains scientists working on atmospheric composition measurements and data analysis. Many presentations in the 'Atmospheric Chemistry, Aerosols, and Climate' session emphasized the bringing together of observations and models in new ways.

Combining theory and observations was a theme of **John Pyle**'s SPARC lecture. Bringing together a mixture of measurements, climate model simulations, and trajectory model calculations, John showed the progress that has been made in narrowing the emissions estimates of very short-lived species (VSLS; *e.g.* bromoform), and understanding their impact on the atmosphere, while highlighting the need for a greater spatial coverage of observations to make more progress.

Using the best estimates for VSLS emissions, model calculations suggest that VSLS contribute about 25% (5pptv) of total stratospheric bromine, contributing a 20% reduction in lower stratospheric ozone in the Southern Hemisphere. With the caveat that little is known about how VSLS emissions might evolve, a future increase in their emissions could slow, but not prevent, ozone recovery.

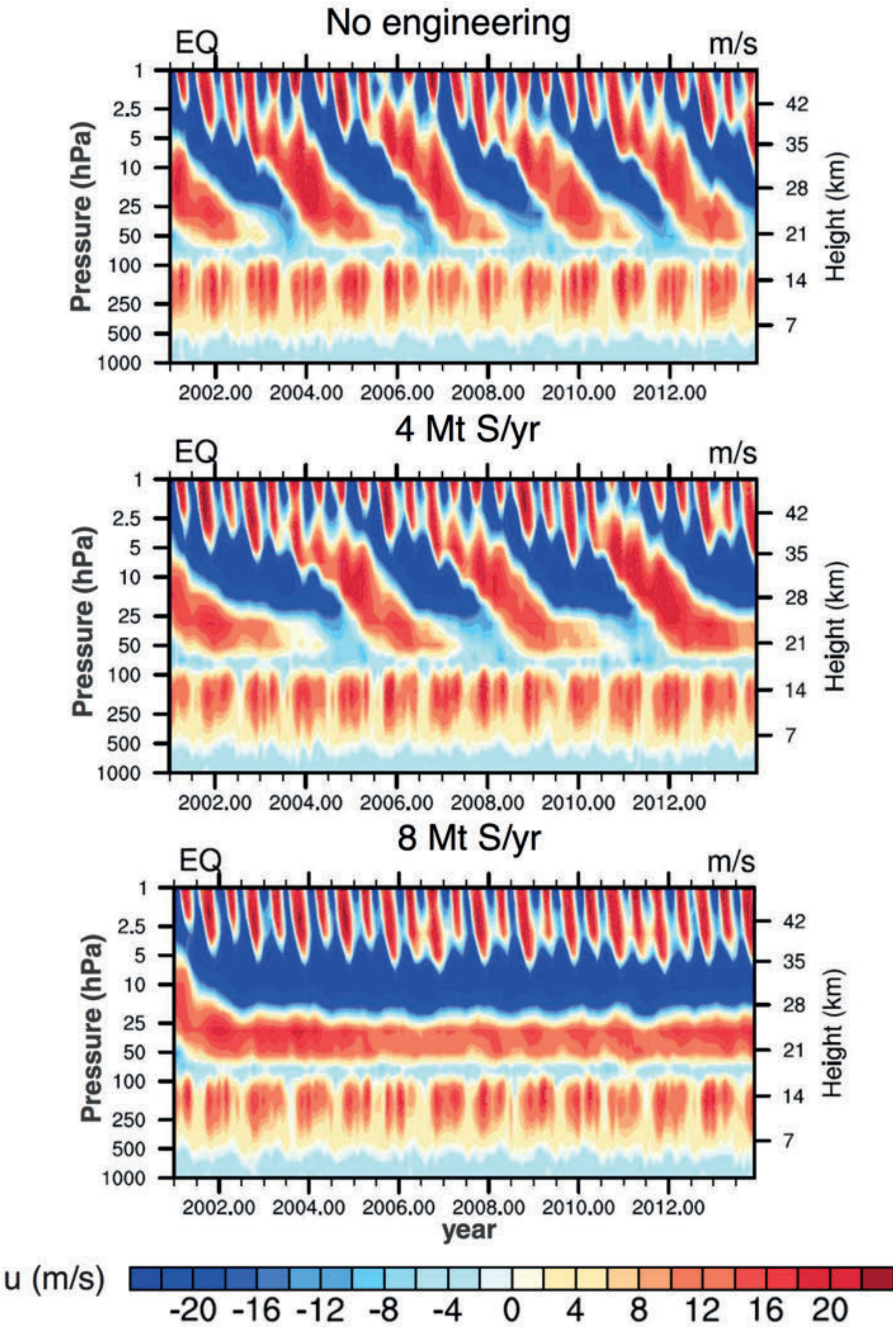
Changing tack, John also presented some chemistry-climate model (CCM) calculations probing the individual effects of the drivers of climate and composition change. The results support the conclusions drawn from recent studies (*e.g.* ACCMIP): through the expected ozone recovery and changes in stratospheric circulation, stratospheric changes will significantly impact tropospheric changes. On this theme, **Jessica Neu** presented a new way to use natural variability in stratospheric and tropospheric ozone arising from the QBO/ENSO to validate stratosphere-troposphere exchange in CCMs. Using several years of satellite observations, Jessica showed that the stratospheric ozone column variability associated with QBO and ENSO explains 16% of the variance in northern hemisphere mid-latitude ozone at 500hPa, and that a 25% increase in stratospheric ozone is associated with a 2% increase in tropospheric ozone. This analysis will be applied to an ensemble of CCMs in the CCMI activity.

Stratospheric changes and links to climate trends and variability was a theme of several presentations. Motivated by the huge Arctic ozone loss in 2011, **Ulrike Langematz** presented model calculations examining projections of future Arctic ozone. The results show that an increased volume of polar stratospheric clouds (PSCs) in early winter, driven by stratospheric cooling, is countered by late spring increases in dynamically driven heating. While individual depletion events could not be ruled out, the calculations suggest no tendency towards more Arctic ozone holes in the future. **Thomas Reichler** discussed temperature-composition feedbacks in an Antarctic context, presenting model calculations showing that Antarctic climate variability has increased by 80% in the stratosphere and 5% in the troposphere due to ozone depletion and the associated photochemical, dynamical, and climatic feedbacks. **James Keeble** isolated the role of Antarctic ozone depletion by "switching off" halogen activation on PSCs in his model. As well as highlighting well-established stratospheric and tropospheric climate signals, the simulations suggest that Antarctic ozone depletion drives more polar downwelling in austral summer, highlighting the potential role for ozone depletion in seasonal trends in the Brewer-Dobson circulation.

Untangling the complexity of composition-climate feedbacks further, **Fiona Tummon** talked through determining the lifetimes of ozone depleting substances (ODSs) in a changing atmosphere, important for quantifying their ozone depletion potential and climate impact. The net effect of changes in climate and ODS emissions is to shorten CFC and HCFC lifetimes by 1-4%, although the climate and emission impacts are of opposite sign for each group of compounds. The lifetimes and properties of shorter-lived compounds (*e.g.* ozone, methane, aerosols) are of particular interest for climate as they are earmarked for near-term climate change mitigation, and near-term climate forcers (NTCFs) was the subject of the invited talk by **Bill Collins**. Due to their short lifetime and decadal-scale climate impacts, NTCFs impact the climate in a spatially non-uniform manner, and there are significant challenges in relating the regional climate response to the regional forcing.

Several talks discussed the impacts of aerosols on climate. Using an array of satellite data, **Graeme Stephens** used his invited talk to describe how a cloud's albedo responds to aerosol through several buffering processes, with the net effect being described by the changes in the cloud's water budget. Perhaps counter intuitively, higher model resolution will not guarantee improved representation of these aerosol effects. **Jason English** showed that describing the aerosol size distribution with a sectional model (as opposed to modal) improves the representation of aerosol evolution after volcanic eruptions. Due to particle size growth, it seems that very large eruptions have self-limiting radiative forcing. For example, despite injecting 100 times more sulfur than Pinatubo, the Toba eruption only had 20 times the effect on aerosol optical depth. Using the same model, **Ryan Neely** demonstrated the major contribution of recent smaller volcanic eruptions to stratospheric aerosol variability, dwarfing the more localized impact of increased Chinese and Indian emissions. In a similar vein, **Chao Li**'s climate model analysis suggested that the recent upward trend in stratospheric aerosol does not help explain the "hiatus" in the global mean surface temperature trend, pointing instead to a negative phase of the Arctic Oscillation. Stratospheric aerosols are often mooted as a mechanism for climate geoengineering,

Figure 2: Does the QBO disappear following geoengineering? Profile time series of zonal mean wind showing lengthened periods of QBO stalling associated with an increased rate of sulfur injection. Results taken from the ECHAM5/HAM chemistry-climate model presented by Hauke Schmidt (from Niemeier *et al.*, in prep.), confirming the results of Aquila *et al.*, 2014).



including in **Hauke Scmidt**'s invited presentation summarizing GeoMIP (the geoengineering model intercomparison project; Kravitz *et al.*, 2013), as a potential method of solar radiation management (SRM). Particular attention was given to the hydrological cycle, and it was shown that SRM overcompensates for the precipitation increase due to higher CO_2. In addition, early results from one model suggest the possibility of destroying the QBO through SRM by increasing stratospheric sulfate aerosols (**Figure 2**).

Stratosphere-troposphere-ocean Dynamics and Predictability of Regional Climate

Dynamics and predictability go hand in hand, and, with SPARC's recent extension into the troposphere, now more than ever. Accordingly, the dynamics session encompassed a broad array of topics, touching on the whole coupled atmosphere-ocean-ice system.

Doug Smith opened the session with an enlightening SPARC lecture on the role of the stratosphere in seasonal to decadal prediction, an area of active and vibrant research. He first outlined the potential sources of skill, including stratospheric warmings, solar variability, and the QBO, as well as traditional tropospheric and surface sources with which the stratosphere is interconnected. After discussing the difficulties inherent in making predictions, he highlighted the promising skill in monthly predictions of the North Atlantic Oscillation and five-year predictions of North Atlantic surface temperatures and storms. With the latest forecasts suggesting cooling in the Atlantic, wet winters and dry summers could be ahead for Europe. Continuing the prediction theme, **Seok-Woo Son** discussed the role of the stratosphere in regional surface prediction in the Southern Hemisphere, asking the question of whether interannual Antarctic ozone variability leads to any significant surface impacts. After removing the slowly varying component of ozone changes, which are primarily due to ODSs, a significant impact of Antarctic stratospheric ozone concentrations in September was found on the Southern Hemisphere surface climate in October. Low ozone years correspond to cooler temperatures over the Antarctic Peninsula, southern South America, and Australia, as well as increased rainfall over Australia (**Figure 3**).

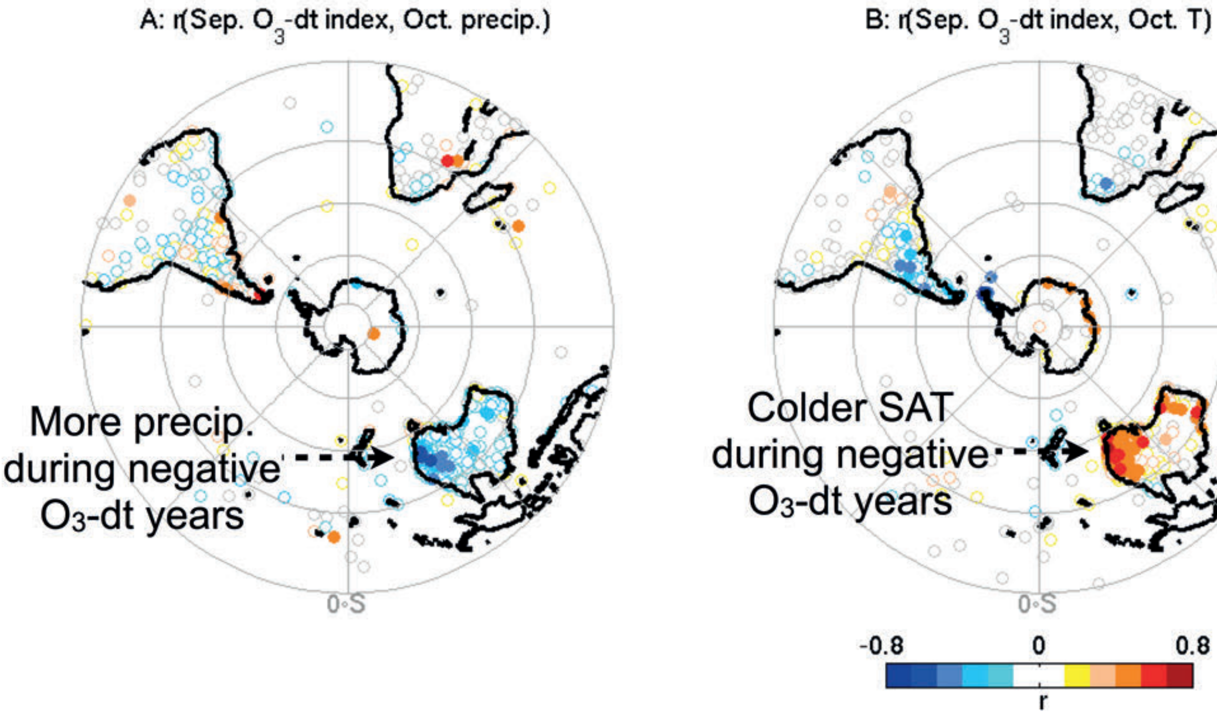


Figure 3: Lag correlation maps between the September O3-dt index and October CRU (A) precipitation, and (B) daily mean temperature. Only stations with data availability of at least 75% of the analysis period are used. The correlation coefficients that are statistically significant at the 95% confidence level are shown by filled circles. A two-tailed t-test is used to test significance. (Figure from: Son *et al*., 2013).

These impacts are comparable in magnitude to those linked with ENSO, suggesting potential for improvement in seasonal prediction for these regions during austral spring. Also focusing on the Southern Hemisphere, **Damian Murphy**, evaluated inertial gravity waves over the polar stratosphere in radiosonde observations at Davis station, Antarctica. Both up- and down-going waves were found in approximately equal number, which cannot be easily explained by a tropospheric source. This suggests that inertial gravity waves over Antarctica are formed from a source process distributed throughout the stratosphere, a source not currently included in models.

Stratosphere-troposphere intraseasonal dynamical coupling was the focus of the next three presentations. **Tiffany Shaw** gave an invited talk on the myriad of possibilities through which tropospheric and stratospheric dynamical variability couple on intraseasonal timescales. She highlighted the importance of both planetary- and synoptic-scale waves, and of both wave absorption and reflection. She then discussed the role of Atlantic sector variability in the generation of sub-polar extreme heat flux events in reanalysis data. Comprehensive general circulation models with biased representations of North Atlantic tropospheric circulation also have biased representations of extreme sub-polar heat flux events. As these events can then subsequently impact the North Atlantic circulation, it can be very difficult to isolate causality without carefully constructed model experiments. **Mark Baldwin** discussed mechanisms for the downward coupling of stratospheric variability to the troposphere. Motivated by the linearity of the tropospheric response to opposite phases of stratospheric variability and by the large surface polar response to stratospheric anomalies, he discussed the ability of stratospheric potential vorticity (PV) anomalies to modulate tropopause height. Specifically, the stratospheric polar column can expand downwards and physically compress the tropospheric polar column, and hence directly modulate winds and temperatures in the polar troposphere. The eventual surface response is stronger than can be explained by this mechanism, but this mechanism may be responsible for the initial downward coupling. Finally, **Amy Butler** discussed the definition of stratospheric sudden warmings (SSWs). After noting the lack of consensus in early literature regarding the definition, and mentioning the nearly ten different classes of definitions of SSWs that exist in the recent literature, she highlighted the importance of an accepted definition in order to robustly assess, for example, whether SSW frequency will change in future or whether decadal variability of SSW frequency occurs. She finished her talk by discussing ongoing efforts towards formulating a new, robust definition that can easily be applied to a wide range of models in both the current and future climate (see more about this in a separate article on page 23).

Ed Gerber gave an invited talk on the Brewer Dobson Circulation (BDC). After demonstrating the importance of waves for the conservation of momentum associated with the BDC, he noted that comprehensive CCMs disagree on the type of wave that is most important for this momentum conservation. Specifically, the wave sources are traditionally broken down into resolved waves, orographic gravity waves, and non-orographic gravity waves, but models agree better on the overall strength of the wave-driving than on the contribution from each of these three sources. In order to resolve this conundrum, he presented idealized general circulation model experiments in which nearly identical total BDCs are maintained by vastly different balances between gravity waves and resolved waves in a controlled environment in which gravity waves are modulated. These nearly identical BDCs occur because of compensation between the waves' sources, which is necessary in order to maintain a stable potential vorticity profile in the stratospheric surf zone. Hence inter-model differences in the waves responsible for the BDC likely do not reflect gaps in our understanding of the BDC, but rather model tuning differences.

After breaking for posters, the session continued its theme of extending from the stratosphere into the troposphere and ocean with two talks on the impacts of Antarctic ozone depletion on the climate system. In an invited lecture, **Cecilia Bitz** provided compelling arguments for why ozone depletion cannot be causing the recent observed increase in Antarctic sea-ice extent. Though there is a clear positive correlation on interannual timescales between the position and strength of the mid-latitude westerlies and sea-ice extent, modelling evidence suggests that the multi-decadal strengthening of these winds due to ozone depletion leads to a decrease in sea-ice extent. She outlined the different mechanisms controlling these fast and slow responses to the wind changes, with the slow response being dominated by enhanced upwelling of warmer waters from below, which increase sea surface temperatures and melt sea-ice. Her talk ended with a cautionary note suggesting that debate on this topic is still continuing. Turning to the impact of these strengthening winds on the ocean, **Darryn Waugh** presented observational evidence for an increase in subtropical ocean ventilation in the Southern Ocean over recent decades. Using measurements of CFC-12, he found an increase in the age of subtropical mode waters and a decrease in the age of circumpolar deep mode waters at similar depths. The changes observed are consistent with theoretical expectations and can be reproduced by models driven with increases in surface westerlies. Open questions remain though, such as what impact these changes may have on oceanic uptake of heat, freshwater, carbon, and nutrients.

The response of the surface westerlies, and in particular of the SAM, to volcanic eruptions was explored by **Kristin Kruger**. Theory suggests that volcanic eruptions in winter should lead to a positive phase of the SAM (increased mid-latitude and decreased polar cap sea level pressures) in the following winter/spring. However, observations and model simulations of recent eruptions show little signal in the SAM and, if anything, the opposite response. Through a variety of sensitivity studies, it was suggested that an injection of >190 mega tonnes of SO_2 was required to show a significant response in the surface SAM, more than ten times larger than that injected by Mt Pinatubo.

The session ended with two talks focused on the Northern Hemisphere. **Kazuaki Nishii** described the relationship between blocking highs and planetary waves, finding a geographical dependence in their interaction. Blocking over North America, the Atlantic, and Europe tends to enhance upward planetary activity, warming the polar stratosphere, while blocking over Asia and the western Pacific tends to suppress planetary activity and cools the stratosphere. Finally, **Alexey Karpechko**, discussed the impact of the large 2011 Arctic ozone loss on tropospheric circulation patterns. While a strong positive phase of the Northern Annular Mode was found, as might be expected from the ozone changes, their experiments suggest that this large dynamical signal occurred primarily through pre-conditioning from sea surface temperatures rather than being driven by the ozone loss itself. A special mention is given here to the session's poster prize winner, **Masashi Kohma**, whose clear and comprehensive analysis of satellite data determined that the frequently simultaneous occurrence of polar stratospheric clouds and upper tropospheric clouds in the Southern Hemisphere is caused by blocking highs.

Coupling to the mesosphere and upper atmosphere

This session was dedicated to coupling processes between the stratosphere-troposphere (ST) and the mesosphere-lower thermosphere (MLT). An example of such coupling occurs through solar variability, which influences both systems in upward and downward directions. Total solar variability has significant impacts on regional climate, and ultraviolet variability changes ozone heating and chemistry in the middle atmosphere. Such changes modify the generation and upward propagation of atmospheric waves, including gravity waves, planetary waves, and tides. Energetic particle precipitation (EPP) from the solar wind and Earth's magnetosphere is another indication of solar influence on the climate. EPP affects ozone chemistry in the stratosphere through the production of NO_x.

In an invited lecture, **Bernd Funke** reviewed current knowledge and future issues for such solar influences on the climate. He introduced recent progress in observations of the change in spectral solar irradiance and in possible EPP estimates through observations of NO_y and OH. He also emphasized the usefulness of ESMs that offer the opportunity to perform sensitivity experiments studying interactions between solar variability and other forcing factors such as the solar-QBO relation, North Atlantic air/sea coupling, the tropical Pacific signal, and ENSO aliasing. **Anne Smith** (invited talk) also discussed coupling processes between the ST and MLT in addition to solar impacts. SSWs and the elevated stratopause events that sometimes occur subsequent to SSWs seem to enhance downward NO_x transport from the MLT. Non-migrating tides dominant in the MLT are excited by tropospheric convection, but in turn, wave propagation and dissipation can be modified by changes in MLT dynamical fields. She also discussed the predictability of the MLT by various nudging experiments using the WACCM model. She showed that the MLT system is not completely deterministic, although ST impacts on the MLT are large. Potential sources of error include expressions of wave generation from instability, gravity waves, and stratospheric variability. This means that continuous observations of the MLT region are needed.

The important role that small-scale gravity waves play in middle atmosphere coupling has been well recognised. As gravity waves are generally too small to be resolved in general circulation models, their effects need to be parameterized. However, global observations of gravity waves are required to improve these parameterizations. **Robert Vincent** characterised gravity wave properties such as momentum flux and phase speeds in the lower stratosphere using super-pressure balloon measurements at high southern latitudes. It was emphasized that in the zonal mean non-orographic gravity waves are as important as orographic gravity waves. **Charles McLandress** quantified gravity wave drag in the CMAM model and compared these results to MLS satellite observations. Results indicated the important role of orographic gravity wave drag prior to major mid-winter SSWs in the Arctic. Continuing the focus on Arctic SSWs in her invited talk, **Gloria Manney** used satellite observations of recent Arctic SSWs to clearly indicate the coupling between atmospheric regions. In particular, the impact of these events on dynamics and trace gas transport throughout the middle atmosphere was elucidated. The interannual and decadal variability of SSW dynamics and minor constituents were also presented.

Wednesday afternoon being free, the theme on coupling to the mesosphere and upper atmosphere had slightly fewer oral presentations but a wide variety of very interesting posters. Some highlights include the following. **Manfred Ern** illustrated that critical-level filtering is the main QBO-related dissipation process for gravity waves, and that enhanced gravity wave drag is observed directly above decaying summer-time mesospheric westward jet instabilities. **Takenari Kinoshita** reported on the tidal periodicity of gravity waves in the mesosphere above Alaska, suggesting that the observed 12-hour phase agreement between the zonal wind and gravity wave kinetic energy is a result of gravity wave dissipation on the tidal field. To look at gravity waves more closely, **Ronald Smith** presented an upcoming experimental project to examine gravity wave generation and propagation above New Zealand. Gravity-wave resolving, high-resolution GCMs also provide a useful tool to examine the dynamics of the middle atmosphere. Using such data, **Takatoshi Sakazaki** showed that dominant non-migrating diurnal tides, DE3 and DW5, are interpreted as inertia-gravity waves excited by convection distributed over the African and American continents (**Figure 4**). The structure and time variation of phases were consistent with satellite observations which cover limited height ranges.

Dieter Peters showed long-term variability of the extra-tropical mesosphere where a strong correlation with the stratospheric QBO was found. **Peter Hitchcock** showed that under a doubling of

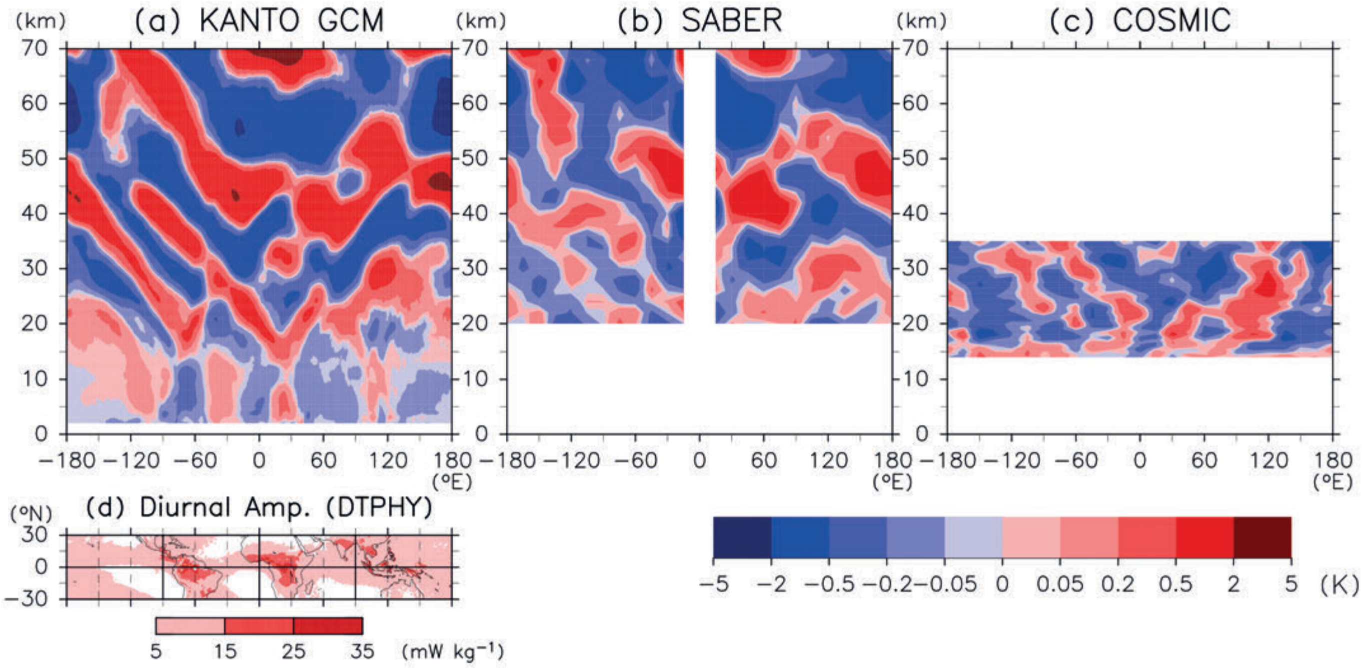


Figure 4: Longitude-altitude section of the annual-mean temperature component of non-migrating tides at 1200UTC averaged for 10°S-10°N, from (a) a high-vertical resolution GCM (KANTO) simulation, (b) SABER observations, (c) COSMIC observations, and (d) latitude-longitude section of annual-mean amplitude of the diurnal harmonic component of diabatic heating averaged for heights of 5-14km from the KANTO model. Both migrating and non-migrating components are included for (d). (Figure from: Sakazaki *et al.*, in prep.).

CO_2, radiative damping is projected to strengthen by 10-30% through most of the stratosphere, which will have an effect on large-scale stratospheric phenomena, including the waves which drive the QBO and recovery from SSWs. Radiosondes and CMIP5 models indicate that the QBO amplitude has weakened in the lower stratosphere in the second half of the 20th century (**Yoshio Kawatani**), providing support for a long-term trend of enhanced upwelling near the tropical tropopause. **Sebastian Schirber** demonstrated a realistic QBO using purely convection-based gravity wave parameterization in the ECHAM6 GCM.

Finally, **Kota Okamoto** examined barotropic/baroclinic instability in the upper mesosphere using high-resolution GCM data. The anomalous latitudinal PV gradient frequently observed in winter is attributable to the poleward shift of (resolved) gravity wave drag in association with the stratospheric jet shift. Large longitudinal dependence of the anomalous PV latitudinal gradient was also indicated.

Observational datasets, reanalyses, and attribution studies

Observations of the meteorology and composition of the atmosphere and their spatial and temporal variability are essential to advancing our understanding of Earth's climate system and its response to natural and anthropogenic changes. In particular, comprehensive long-term records underpin reliable assessment of climatological behaviour, attribution of trends, and evaluation of the risks of extreme climate anomalies and events. **Karen Rosenlof** opened the session with a SPARC lecture exemplifying this theme. Her talk illustrated how measurements of key quantities such as water vapour, ozone, and temperature can be used to study the stratospheric mean meridional circulation, commonly referred to as the BDC, which cannot be measured directly but is inferred from constituent observations. After a historical overview summarizing how measurements of trace species elucidated mass transport in the stratosphere, she highlighted the abrupt ~2°C drop in zonally averaged temperatures observed at the tropical cold point at the end of 2000. This was associated with a change in the strength of the BDC near the tropical tropopause, and she further discussed the significant impact that these changes may have had on climate. She ended the talk by noting that much is still to be learned about variability in the BDC, and that continued global observations of stratospheric trace gases and temperature are critically important if we are to accurately predict how stratospheric circulation will respond to changes induced by greenhouse gases (GHG) or solar radiation management.

Three talks examined long-term ozone datasets. **David Tarasick** presented a homogenized record of Canadian ozonesondes from 1996 to 2012 and showed that interannual variability and long-term changes in free tropospheric ozone are correlated with those in the lower stratosphere, suggesting that tropospheric ozone concentrations over mid-latitude sites in Canada are strongly influenced by stratospheric intrusions. **Richard Stolarski** analysed 36 years of Solar Backscatter UltraViolet (SBUV) satellite measurements derived from several instruments using a common data processing algorithm in which ozone amounts are retrieved in broad upper and lower stratospheric layers. In the upper stratosphere, the SBUV data showed an upward trend in ozone in addition to that attributable to ODSs, consistent with the fact that GHG-induced cooling slows ozone loss in that region. In the lower stratosphere, the data indicated decreases in ozone at all latitudes, contrary to the expectation that changes in circulation strength would lead to increases in ozone at middle and high latitudes; thus no signature of circulation speed-up was detected in the SBUV data. In an invited talk, **Mark Weber** also explored the coupling between chemical and dynamical effects on ozone and the impact of variability and trends in the BDC on detection of ozone recovery. Using satellite total ozone observations in both hemispheres from the merged GOME/SCIAMACHY/GOME-2 dataset (1995–2010), he found a compact linear relationship between the winter-mean extra-tropical 100hPa eddy heat flux (a measure of BDC strength) and the ozone spring-to-fall ratio (**Figure 5**); that a similar relationship is seen in chemistry climate models suggests that current models realistically describe stratospheric circulation variability and its effect on total ozone. Future changes in the modelled relationship indicate a shift from ODS-related ozone recovery to a regime in which GHG changes dominate in the second half of the 21st century. While positive ozone trends in the upper stratosphere (40–45km) derived from satellite limb measurements over the last decade may be indicative of recovery, negative ozone trends in the tropical middle stratosphere (30–35km)

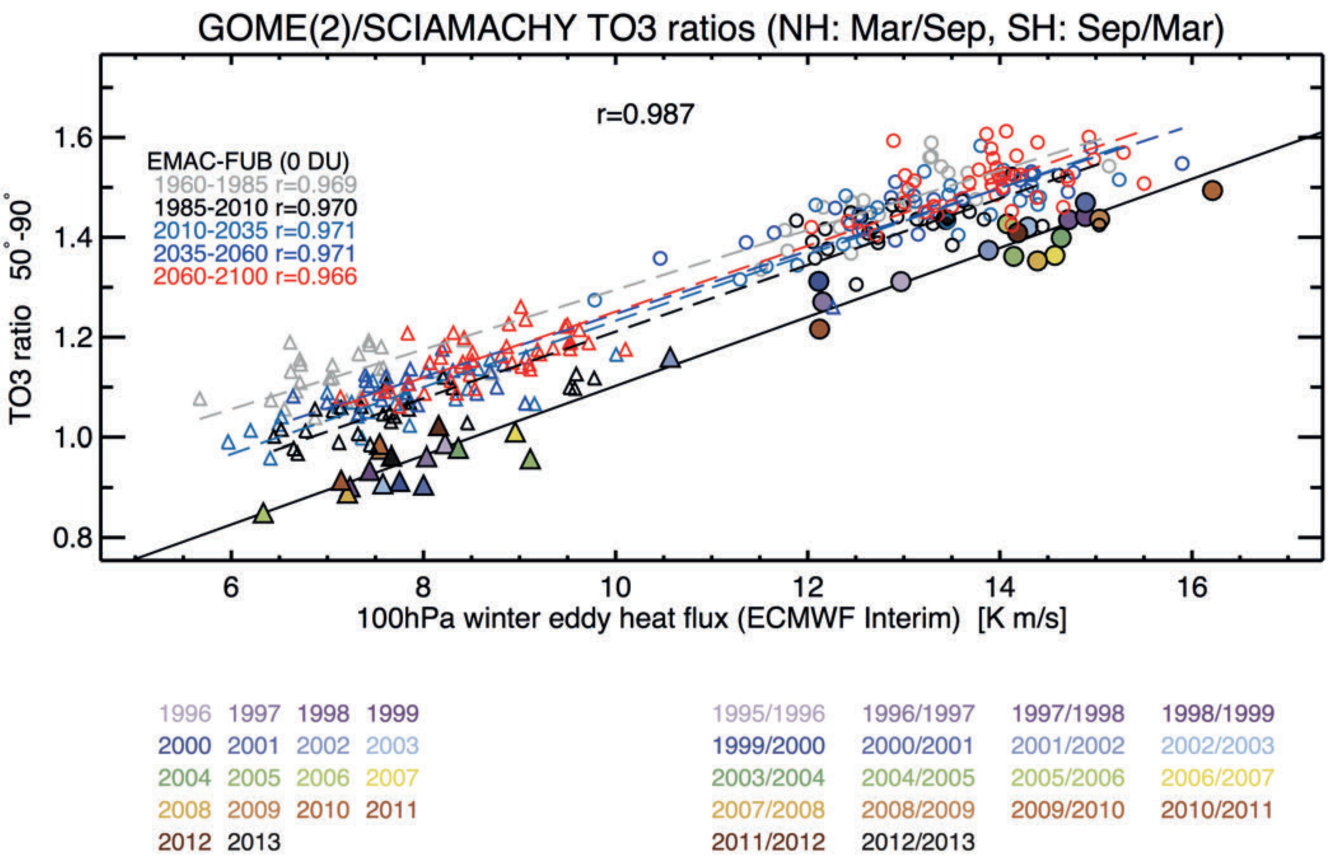


Figure 5: Spring-to-autumn ratio of polar cap total ozone as a function of absolute extra-tropical winter mean eddy heat flux for both GOME2/SCIAMACHY and the EMAC-FUB model. Southern hemisphere data is shown using triangles, the northern hemisphere with circles. The different colours correspond to different periods/years. (Figure updated from: Weber et *al*., 2011).

are possibly linked to changes in NO_x. In another talk based on satellite observations, **Gabriele Stiller** reported on the status of the SPARC Water Vapour Assessment II (WAVAS II) initiative, which will provide an intercomparison and quality assessment of satellite water vapour datasets, with the ultimate aim of producing a consistent multi-instrument data record covering the last 30 years.

Meteorological analyses were the focus of two presentations. **Gilbert Compo** gave an invited talk on developing the 20th Century Reanalysis version 3 (20CRv3); an international project to produce global states of the atmosphere, land, and ocean spanning the period from 1850-2013 using an Ensemble Kalman Filter and assimilating only surface pressure observations. The previous version of the historical reanalysis (20CRv2), which provides near-surface to tropopause, 6-hourly fields at 2-degree spatial resolution as well as estimates of the dataset's time-varying quality, is useful for a broad range of climate applications. These include validating climate models, determining storminess and storm track variations over the last 150 years, understanding historical climate variations, and estimating risks of extreme events. 20CRv3 improvements include higher spatial resolution, a better-resolved stratosphere, increased observational density, and a companion ocean reanalysis.

Masatomo Fujiwara performed multiple linear regression analysis on monthly-mean zonal-mean temperature from nine atmospheric reanalyses to investigate the global climate response to major volcanic eruptions over the 1958–2009 period. Most reanalyses showed statistically significant warming in the tropical lower stratosphere following the eruptions of both Pinatubo and El Chichón, but only the Pinatubo eruption produced significant cooling in the tropical troposphere; the response to the eruption of Mt. Agung was asymmetric about the equator, with warming in the Southern Hemisphere mid-latitude upper troposphere/lower stratosphere (UTLS).

Finally, **David Karoly** closed the session with an invited review that underscored the necessity for both high-quality long-term observational datasets and reliable climate model simulations in trend detection and attribution studies. Such studies have allowed quantification of the anthropogenic contribution to observed changes in annual global mean surface temperature. Compared with the surface and troposphere, fewer detection and attribution studies have been applied to the role of the stratosphere in recent climate changes because limitations in observational and modelling datasets and large internal variability complicate attribution of stratospheric changes. Examples shown include attribution of observed trends in lower stratospheric temperature and springtime tropospheric zonal wind in the Southern Hemisphere to Antarctic ozone depletion.

Tropical Processes

Tropical processes are an important component of UTLS studies since the tropics act as a gateway to the stratosphere. Future climate change is expected to change boundary conditions for transport and chemistry in this region and, for example, influence the Indian and Asian monsoons. The session included ten oral presentations, four of which were invited, and a number of posters. In an invited talk, **Masakazu Taguchi** examined aspects of tropical and extra-tropical connections associated with the QBO, modulation of the QBO especially by ENSO, and effects of the QBO and ENSO on the northern hemisphere winter stratosphere. He showed that frequency or probability of major stratospheric sudden warmings (MSSWs) show non-linear changes with ENSO and QBO and emphasized that understanding the mechanisms responsible for these effects will be a challenge.

Ji-Eun Kim presented a new wave scheme for trajectory modelling of stratospheric water vapour. A consequence of the exponential dependence on saturation mixing ratios with temperature is that realistic representations of temperatures in reanalysis datasets are critical to dehydration simulations. The new scheme results in enhanced wave amplitudes of those currently under-represented in reanalyses, thereby maintaining wave variability that would otherwise be absent. This has important implications for improving tropopause temperatures and saturation processes along trajectories in the tropical tropopause layer.

Erik Johansson examined how the vertical structure in cloud radiative heating is related to Indian monsoon activity using five years of CALIPSO and CloudSat data. The heating contribution is greatest for high clouds followed by alto- and nimbostratus and then by deep convective cores. While the latter have the strongest heating, they are infrequent compared to other cloud types. Strong differences are also noted between pre- and post-monsoon periods and between

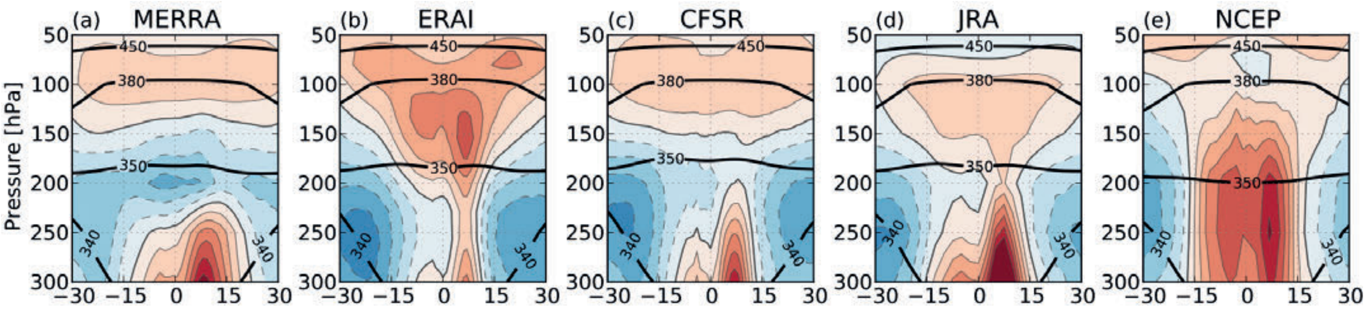


Figure 6: Zonal mean total diabatic heating averaged from 2001-2010 for (a) MERRA, (b) ERA-Interim, (c) CSFR, (d) JRA, and (e) NCEP reanalyses. This figure illustrates that the uncertainty in the total diabatic heating in the UTLS region from reanalyses is so large that it cannot be used to constrain the vertical upwelling in this region. (Figure from: Wright and Fueglistaler, 2013).

eastern and western regions of the subcontinent. **Andrew Gettelman** (invited) presented the current state of knowledge of cloud formation processes in the tropical tropopause layer (TTL) and reviewed how they are represented in CCMs, which represent the TTL structure well but cloud microphysics are a notable weakness. Ice nucleation mechanisms, while essential to represent cloudiness and dehydration, are particularly difficult to simulate. He indicated that tropical tropopause temperatures are expected to increase as a consequence of anthropogenically produced climate change. Improving models requires new and unique observations to target our knowledge gaps. In describing the relationship of the Asian Summer Monsoon to the UTLS, **Keasava Mohanakumar** (invited talk) showed how water vapour is transported to the lower stratosphere with large-scale spatial and temporal variability. The QBO seems to modulate the monsoon circulation by enhancing the monsoon low-level jet during its westerly phase. The rapid warming of the equatorial Indian Ocean and upper tropospheric cooling in the Tibetan anticyclone region causes a decrease in the strength of the tropical easterly jet stream in the upper troposphere, which in turn causes a change in the summer monsoon rainfall pattern.

Stephan Fueglistaler showed how the assumption of dehydration following the Clausius-Clapeyron relation in TTL air parcels leads to a dry bias in comparison to observations and that the Lagrangian dry point was spatially and temporally highly variable. He defined the 'residence time' effect that lowered the stratospheric entry level of water vapour as the circulation strengthened and, hence, improved agreement with observations. The net effect of dehydration can thus vary with constant cloud microphysics. **Felix Bunzel** indicated that mixing processes prevent one-to-one correspondence between stratospheric age-of-air and residual circulation transit times. He showed how the two-way mixing of air parcels between the tropics and extra-tropics increases air-parcel age-of-air values. Equilibrium climate model runs suggest a constant mixing efficiency as residual mass flux increases. However, CCMVal-2 models exhibit strongly varying efficiency that may be due to different model dynamics (*e.g.*, wave spectrum) and/or numerics (*e.g.*, advection scheme, or diffusivity).

Bernard Legras (invited talk) gave a comprehensive review of transport across the TTL and showed that the South Asia Pacific warm pool region is a main contributor to TTL air parcels throughout the year, with combined maritime convection always the dominant source. Trapping within the Asian Monsoon Anticyclone is most effective for parcels transported by convection over the Tibetan plateau and continental Asia north of 20°N. Key remaining transport issues are the need to validate reanalysed winds and heating rates (see for example **Figure 6**), the importance of sub-grid-scale high-frequency motion, and a quantitative estimate of detrainment from convection. **Robyn Schofield** discussed mass fluxes and detrainment over the maritime continent noting that the representation of convection is important for closure in many biogeochemical cycles. Convection transports a large fraction of bromine and sulfur species as well as CFC-substitute gases aloft. Comparisons of convective mass fluxes over Darwin, Australia, from the WRF model and the 3-hourly ERA-Interim archived values for mass flux and detrainment (representative of observational/coarse model convection) reveal significant differences. Correct representation of convective mass fluxes will require turbulence resolution.

The last presentation of the SPARC General Assembly was given by **Debashis Nath**, who presented an analysis showing an increase in potential vorticity intrusion (PVI) events into the tropics over the last several decades using reanalysis datasets. He proposed a mechanism that involves a shift in warm tropical sea-surface temperatures westward from the eastern Pacific, which affects the Walker circulation and increases the strength of equatorial westerlies in the central Pacific. The PVI trend enhances convective activities in the tropical Pacific sector and affects the dynamics over the tropics.

Some Final Words

Overall, the 5th SPARC General Assembly was an outstanding event and a clear reflection that SPARC is thriving. The meeting, as well as SPARC's general direction, is benefitting from the extended focus on stratosphere-troposphere processes and their role in climate. Example questions that SPARC will work on in future include: How important is interactive chemistry for surface climate prediction? How much does UV irradiance vary across the solar cycle, and what influence does this have on climate? What is the role of the stratosphere in persistent systematic model biases? What are the regional impacts of stratospheric geoengineering? Through what mechanism(s) does the extra-tropical stratospheric circulation affect the surface? What is the role of the stratosphere in the surface temperature 'hiatus'? Do changes in the cryosphere impact the stratosphere-troposphere system? The science presented at the 5th SPARC General Assembly provided a clear indication that we are making steps in the right direction to answer these questions and that SPARC as a whole is continuing to evolve in response to the challenges of a changing world.

The success of the 5th SPARC General Assembly was possible only because of the many hours dedicated by many people. Special thanks are owed to the local organising committee that was chaired by Greg Bodeker and supported by Emma Scarlet, Karin Kreher, and Stefanie Kremser for all their hard work and the huge amount of time invested. We also thank the SPARC Project Office and the WCRP Joint Planning Staff for their help in organising the event. The financial support of all the SPARC General Assembly sponsors, which helped bring a large number of young scientists and scientists from developing nations to New Zealand, is also very gratefully acknowledged. They are: WCRP, WMO, WIGOS, GAW, WWRP, NSF, APN, CSA, ARC, NIWA, ESA, SPARC Project Office, Antarctic New Zealand, COSPAR, Tofwerk, Aerodyne Research, Bodeker Scientific, Macquarie University, and the University of Otago.

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New Efforts in Developing a Standard Definition for Sudden Stratospheric Warmings

Amy H. Butler[1,2], Edwin P. Gerber[3], Dann Mitchell[4], and William Seviour[4]

[1]Cooperative Institute for Research in Environmental Sciences/University of Colorado, Boulder, CO, USA, **amy.butler@noaa.gov**, [2]National Oceanic and Atmospheric Administration/Earth System Research Laboratory/Chemical Sciences Division, Boulder, CO, USA, [3]Center for Atmosphere Ocean Science, Courant Institute of Mathematical Sciences, New York University, NY, USA, [4]Department of Physics, University of Oxford, Oxford, UK

Sudden stratospheric warmings (SSWs) are explosive temperature increases in the wintertime stratosphere that occur within a week or less. They have substantial impacts on the entire atmosphere, from the mesosphere all the way down to the surface. The World Meteorological Organization (WMO) definition for SSWs is frequently referred to in analysis of both stratospheric observations and model simulations. There is no clear reference for this definition, however, and confusion about the details of the calculation, even among scientists who study stratospheric dynamics, has led to various interpretations of the definition (Butler *et al.*, 2014, submitted to BAMS).

There are a number of reasons to re-examine the standard definition for SSWs: (1) The definition was developed in the 1960-70s, based largely on the observation system at the time (radiosondes/rocketsondes). It therefore does not take full advantage of the more comprehensive observations available now. (2) Our theoretical understanding of SSWs has also matured considerably in recent decades. The definition could be improved to include, for example, differences between split- and displacement- type events, or guidance on how to determine whether closely-timed events are independent. (3) A number of new diagnostics have been proposed in the last decade to characterize extreme variability in the stratosphere (in addition to different interpretations of the current definition), leading to inconsistencies in the classification of major SSWs depending on which diagnostic is chosen.

Many attending the SPARC DynVar meeting, held from 22-24 April 2013 in Reading, UK, expressed interest in comparing current methods used to define SSWs, and attempting to formally update the current standard definition, either via SPARC or WMO channels. In response to this interest, a lunchtime discussion was held during the SPARC General Assembly on 16 January 2014, in Queenstown, New Zealand. This discussion was led by **Amy Butler**, **Edwin Gerber**, and **Daniel Mitchell** (transcription by **William Seviour**), with approximately 25 people in attendance.

The goals of the meeting were to bring about awareness of these efforts, and to begin to gather input from the community about what is desired from a definition for SSWs and how it will be used. For example, is it important to classify the SSW onset in real time? Is it a priority to capture the stratosphere-troposphere coupling of an event in the definition? Is it important to keep the definition simple to implement? A survey in addition to the informal discussion was gathered on these topics and anonymous responses are reported here.

A proposed methodology and timeline for gathering input from the community was first discussed (**Edwin Gerber**). This process will involve first advertising the efforts through SPARC, known email lists, websites, and word of mouth. **Kirstin Krüger** suggested reaching out to communities beyond stratospheric dynamics, including experts in the upper atmosphere, ozone/chemistry, and weather prediction, who might also use the SSW definition. **Daniel Mitchell** proposed that an email list specifically for this project should be created, along with a website, blog, or forum for people to carry out discussions about the definition over the next year (the forum and e-mail list are now active – see web link below). Two side meetings are being considered to focus efforts in 2015: one at the AMS Middle Atmosphere meeting in January 2015, Phoenix, Arizona, USA, and one at the EGU General Assembly in April 2015, Vienna, Austria. An additional small meeting or teleconference may be necessary to bring together results and conclusions during the summer of 2015. A consensus paper would then be written in late 2015 following an open comment period of a few months. Eventually, more formal recognition of the changes (if desired by the community) might be requested through SPARC or through the WMO (the WMO Commission for Atmospheric Sciences will not meet formally again until ~2017-18).

Opinions on this proposed process were generally positive, and the majority agreed that some updates to the standard definition are necessary for increased clarity and to represent the changing needs of the community.

An open discussion was then started on SSW definitions. The first part of the discussion involved conferring about the details of the current WMO definition. Representatives of the group tied to the original development of the WMO definition suggested that the definition (including various manifestations of SSWs, *e.g.*, minor, major, Canadian, and final) is described clearly in work by Labitzke and others at Free University Berlin (**Kristin Kruger**, **Ulrike Langematz**), and that this definition should be clarified and emphasized to the community. Others pointed out that certain guidelines needed for the computation of these events remain unclear, such as separation of independent events or the meaning of "mid-winter" warmings versus final warmings, and that the code for the calculation of SSWs should be provided publicly (**Amy Butler**, **Edwin Gerber**). It was stressed (**Edwin Gerber**, **Dian Seidel**) that the default position would be to leave the definition as is, and simply add clarification on the calculation or additional information regarding determination of the type of event. Others agreed with this point, suggesting that any substantial changes to the definition would require more research and time. **Daniel Mitchell** suggested a two-tier definition: the first tier would be the basic SSW definition; the second tier would include further information to allow for the separation of split versus displacement-type events, final warmings, or Canadian warmings. The latter could also potentially include measures of stratosphere-troposphere coupling.

Seok-Woo Son brought up the question whether having a standard definition is necessary. **Gloria Manney** suggested that having a standard definition is at least useful for comparing stratospheric variability in reanalyses or model simulations, and the majority of attendees agreed on the utility of a standard definition. **Shigeo Yoden** and **Tiffany Shaw** mentioned that a standard index of stratospheric variability, in which SSWs and strong vortex events are the extreme tails of the index PDF distribution, may be more useful for the community as it allows a continuum of events. This index would be analogous to, for example, the Niño-3.4 index used to classify El Niño and La Niña events. **Gloria Manney** and **Mark Baldwin**, among others, argued that the definition should not be based on the coupling to the troposphere so that the definition remain applicable to a broad range of research areas.

Finally, we discussed whether the definition needs to take into account changes in the background state due to climate change. There were two views expressed: (1) we should consider adjusting the index to account for climate change, or else changes in SSW frequency may be due solely to changes in background conditions and not changes in dynamical variability (*i.e.* in the waves driving the events); or, (2) we should *not* adjust the index, given that the current definition is based on Charney-Drazin criteria, and the dynamics following these conditions are physically independent of the background state.

We are encouraged by this meeting and the discussions it generated during the SPARC General Assembly. Those who would like to be involved in this process in the future should visit the dedicated webpage **https://sites.google.com/site/stratosphericwarmings/**, and follow the links there to join the e-mail list.

Report on the 1st Stratospheric Sulfur and its Role in Climate Workshop

Larry W. Thomason[1], Stefanie Kremser[2], Markus Rex[3], Claudia Timmreck[4], and Jean-Paul Vernier[5]

[1]NASA Langley Research Center, Hampton, VA, USA, **l.w.thomason@nasa.gov**, [2]Bodeker Scientific, New Zealand, [3]Alfred Wegener Institute Helmholtz-Zentrum für Polar- und Meeresforschung, Telegrafenberg, Germany, [4]Max-Planck-Institut für Meteorologie, Hamburg, Germany, [5]Science Systems and Applications Incorporated, Hampton, VA, USA

A Stratospheric Sulfur and its Role in Climate (SSiRC) workshop was held in Atlanta, Georgia, USA, from 28-30 October 2013 at the Georgia Tech Global Learning Center. The meeting was attended by 64 scientists from 12 countries and included a large number of students and post-doctoral scientists. The workshop program was composed of oral and poster presentations as well as breakout groups and plenary discussions. Presentations from the workshop can be found at **http://www.sparc-ssirc.org/**.

Larry Thomason opened the workshop with a brief presentation on meeting logistics and acknowledgements to our hosts at Georgia Tech, particularly Ray Wang. He also presented a brief history of SSiRC and the motivation behind SSiRC as a new SPARC activity. He discussed the strong effect that stratospheric aerosol can have on surface climate and that processes which maintain the non-volcanic component of the stratospheric aerosol layer are not well understood. In addition, he pointed out that it is clear that some crucial sulfur-bearing species are not well measured at the tropopause and transport rates into the stratosphere are poorly quantified. The primary goal of SSiRC is to facilitate determined scientific studies and measurement campaigns to fill some of these current gaps.

Satellite, aircraft and in-situ measurements

The session on measurements opened with a historical overview of the University of Wyoming optical particle counter (OPC) measurements presented by **Terry Deshler**. Beginning with flights in the early 1960s, the OPC has developed into an increasingly more capable device and has been one of the backbones of stratospheric aerosol observations. The *in situ* measurements at Laramie, Wyoming, USA, and elsewhere provide a measure of the evolution of stratospheric aerosol over the past 40 years, illustrating the impact of past major volcanic events on stratospheric aerosol concentrations as well as the recent minor events (**Figure 7**). Long-standing differences between the OPC estimates of aerosol extinction coefficient and those measured by SAGE-II during non-volcanic periods have been substantially mitigated by correcting an OPC counting efficiency issue. In addition, differences in estimated aerosol surface area density (SAD) have also been substantially reduced, primarily due to the change in SAD algorithm between SAGE-II versions 6.2 and 7.0.

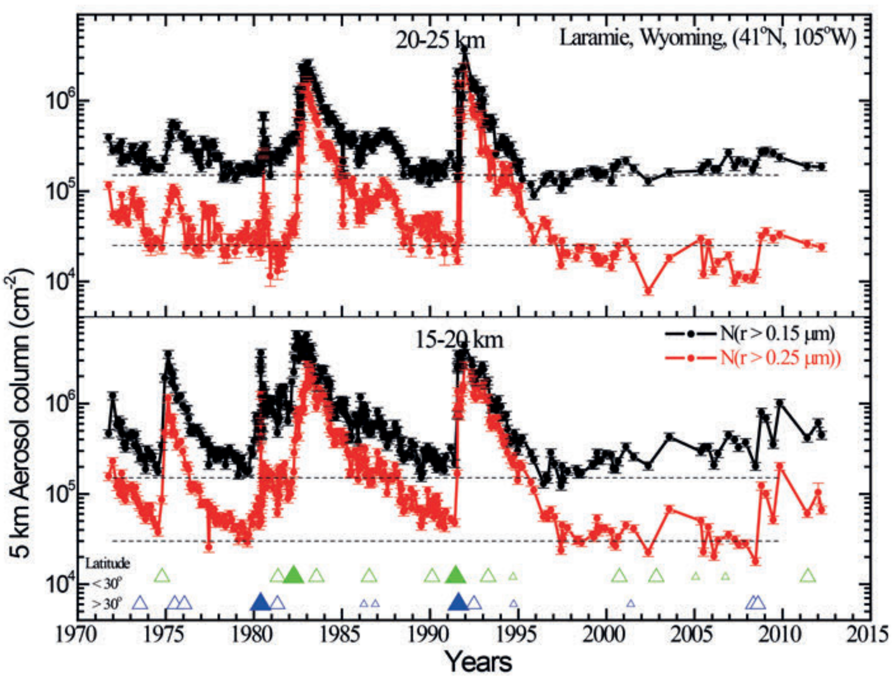

Figure 7: Optical particle counter (OPC) observations at Laramie, Wyoming (courtesy Terry Deshler).

Marc von Hobe used sulfur dioxide (SO_2) and ozone (O_3) observations made during SCOUT-O3 in November/December 2005 in the western Pacific, to show that SO_2 was higher in clean air (apart from clear pollution events) perhaps as a result of longer lifetimes due to reduced hydroxyl (OH) concentrations in this region. However, the concentration of SO_2 remained nearly a factor of three less than that of carbonyl sulfide (OCS, a crucial stratospheric sulfur source species), and he concluded that transport of reduced sulfur compounds through the "OH Hole" is unlikely to represent a major source of stratospheric sulfur.

Markus Rex gave **Jianchun Bian**'s presentation, showing results from an extensive balloon-based campaign from Lhasa and Kunming, China, during the Asian monsoon seasons of 2012 and 2013. In addition to standard meteorological measurements, the balloon payloads included the Compact Optical Backscatter Aerosol Detectors (COBALD), NOAA Frost Point Hygrometers, Cryogenic Frost Point Hygrometers, and Electrochemical Concentration Cell Ozonesondes. The COBALD observations confirmed the presence of the Asian Tropopause Aerosol Layer (ATAL).

Hans Schlager discussed measurements of gaseous sulfuric acid (H_2SO_4) that are planned for the StratoCLIM field campaign taking place in mid-2015, which aims to study local H_2SO_4 production and loss processes. The only *in situ* measurements of H_2SO_4 in the stratosphere reported so far have been performed using passive chemical ionization mass spectrometry (PACIMS), which is based on measurements of the negative ion composition to derive gas-phase H_2SO_4 concentrations.

Roisin Commane discussed measurements of OCS fluxes from both its largest source (the ocean) and sink (the terrestrial biosphere). She presented measurements of OCS eddy covariance fluxes over the open ocean on a ship platform, which, contrary to expectations, showed higher concentrations of OCS and CO_2 over the open ocean than over coastal areas of enhanced biological activity. She also presented the first eddy flux measurements of OCS that span an entire seasonal cycle for a mid-latitude mixed forest.

John Barnes discussed the evolution of the NOAA Mauna Loa lidar that was one of earliest systems to begin regular monitoring of stratospheric aerosol. A recent comparison with the NASA CALIOP space lidar showed excellent agreement in the summer, but a significant offset in winter, with the lidar biased high compared to CALIOP, primarily due to problems in the construction of the density profiles used in the data processing. An updated version is in preparation.

Simon Carn reported on ongoing efforts to catalogue significant volcanic SO_2 emissions into both the stratosphere and troposphere using satellite remote sensing measurements from the UV TOMS (Total Ozone Mapping Spectrometer), OMI (Ozone Monitoring Instrument), and OMPS (Ozone Mapping and Profiler Suite) instruments from 1978 onwards. He showed that actual altitudes of SO_2 injection can differ substantially from reported eruption column heights, and hence plans are underway to use the UV satellite SO_2 measurement archive to generate an altitude-resolved inventory of volcanic SO_2 emissions.

Michael Hoepfner presented some new results from MIPAS that can be used to derive global datasets of SO_2 and OCS for the 2002-2012 period. The SO_2 measurements highlight several features of stratospheric SO_2 distribution: the local maximum of SO_2 at around 25-30km, a precursor of the Junge layer resulting from the downwelling of SO_2-rich air at high latitudes during winter; and SO_2 depletion during spring, which causes the sudden appearance of enhanced aerosol concentrations during this season. The OCS measurements show large variability, revealing significant altitude- and latitude-dependent trends.

Stratospheric aerosol retrievals from SCIAMACHY limb-scatter observations were presented by **Lena Brinkhof**. These measurements agree well with SAGE-II during the overlap period (2002-2005). The aerosol product from 2002-2012 shows a number of volcanic and bushfire events in the lower stratosphere (~18km). In the middle stratosphere, a seasonal cycle (at ~26 km) and biennial variation (at ~32 km) in aerosol levels were observed, both signatures of dynamical processes.

Didier Rault used OMPS measurements to assess the stratospheric aerosol layer from cloud top to 40km. OMPS products include the aerosol extinction vertical profile and an Angstrom coefficient. He showed several interesting features in the OMPS aerosol dataset including the Russian meteor plume, volcanic dust dissipation, transport of aerosol out of the tropical pipe, as well as evidence of the Brewer Dobson Circulation.

Adam Bourassa presented a review of the aerosol retrieval algorithm and highlighted the strengths and weaknesses of the OSIRIS (Optical Spectrograph and InfraRed Imager System) aerosol extinction dataset. He showed a comprehensive comparison with SAGE-II measurements, which have four years of overlap with the OSIRIS mission, and found generally good agreement. This agreement demonstrates the feasibility of creating a merged SAGE-II/OSIRIS stratospheric aerosol time series spanning nearly three decades.

Larry Thomason showed that the earliest Stratospheric Aerosol Measurement (SAM) observations of stratospheric aerosol showed the influence of the 1975 eruption of Volcán de Fuego on stratospheric aerosol extinction and that observations of episodic volcanic events followed by extended recovery remained a significant theme in the SAM/SAGE series. He discussed the role of the SAM/SAGE series in highlighting issues such as the wintertime stratospheric polar vortex being isolated from the mid-latitudes, the existence of the tropical pipe, long-term trends, and the potential for an anthropogenic component to stratospheric aerosol levels.

Christine Bingen presented results from an improved GOMOS (Global Ozone Monitoring by Occultation of Stars) retrieval algorithm that produces superior aerosol products compared to earlier versions. She discussed the inclusion of this product in the stratospheric aerosol activities of ESA's aerosol CCI project, whose goal is to facilitate improvements to existing datasets and the ability to develop merged products with improved consistency, stability, and error characterization.

Transport and Process modelling

This session started with **William Randel**'s overview of the large-scale circulation, transport, chemistry, and aerosol behaviour of the Asian monsoon anticyclone. The anticyclone is a climatological feature of the Upper Troposphere and Lower Stratosphere (UTLS), and a dynamical response to latent heating in persistent monsoon convection. Deep convection also transports constituents to the upper troposphere, which are then confined by the strong anticyclonic circulation. The vertical transport reaches the lower stratosphere (as seen in satellite-derived constituent measurements of CO and HCN, for example), although the contribution of large-scale circulation *versus* deep convection to this transport pathway is poorly understood. Enhanced aerosols are also observed in the monsoon UTLS region, linked to background and volcanically-enhanced periods.

An ensemble of ECHAM5-HAMMOZ simulations for a boreal summer season was analysed by **Suvarna Fadnavis** to investigate the transport of aerosols in the UTLS during the Asian Summer Monsoon (ASM). The model simulations show persistent maxima in black carbon, organic carbon, sulfate, and mineral dust aerosols within the anticyclone in the UTLS throughout the ASM period from July to September, when convective activity over the Indian subcontinent is highest.

Jean-Paul Vernier showed that a recurrent aerosol layer (the ATAL) existing between 13-18km and associated with the ASM, is apparent in satellite observations from SAGE-II and CALIPSO. He showed that a 15-year record comprised of SAGE-II and CALIPSO observations from 1998-2013 showed a positive trend in ATAL aerosol extinction levels that follow the increase of boundary layer pollution over the past two decades.

Duncan Fairlie used CALIPSO measurements, together with a Lagrangian trajectory model and radiative transfer calculations, to study the dispersion of volcanic aerosol from the eruption of Mt. Nabro (Ethiopia/Eritrea) in June 2011. He showed that quasi-isentropic differential advection can explain the observed stratospheric volcanic aerosol layers observed in the anticyclone during the first 10 days following the eruption. He found no direct evidence that deep convection in the Asian monsoon played a key role in transporting volcanic material to the lower stratosphere. Also looking at the Mt. Nabro eruption, **Sabine Griessbach** presented a technique to detect aerosol in MIPAS observations and to discriminate between ice clouds, volcanic ash, and sulfate aerosol. Using the new MIPAS volcanic sulfate aerosol product together with trajectory calculations, she used a case study of the Mt. Nabro eruption, to provide insights into the Asian monsoon circulation.

Stephan Fueglistaler focused on the impact of aerosol on circulation during the Pinatubo period, when the ERA-Interim reanalysis indicates a highly anomalous diabatic residual circulation in the tropical tropopause layer (TTL). This anomalous dynamical forcing counteracts the radiative heating of the volcanic aerosol, and may lead to an underestimation of the aerosol radiative heating by about a factor of two if only the temperature evolution is considered without the dynamical context. Ultimately, the observed temperature change in response to an increase in aerosol is a highly complex response and it is not clear how well models reproduce the dynamical response.

Mian Chin investigated the anthropogenic and volcanic contributions to sulfate aerosol in the stratosphere through modelling and analysis of satellite data for the period 2000-2009, during which a number of small volcanic eruptions occurred. She found that, while the increase of anthropogenic emissions in Asia is important in the upper troposphere, the volcanic sources are likely to be more responsible than the anthropogenic sources for the apparent positive trend in stratospheric aerosol in the past decade. Also using model simulations, **Ryan Neely** presented the impact of global and regional SO_2 sources of the ATAL and the importance of non-sulfate constituents in its composition. He concluded that while the ATAL is largely of anthropogenic origin, it is not solely due to emissions from Asia. The results indicate that Chinese and Indian emissions contribute only ~30% of the sulfate aerosol extinction to the ATAL during volcanically quiescent periods.

Ru-Shan Gao presented in situ measurements of OH, hydroperoxyl (HO_2), and other chemical species made in the TTL in the central Pacific from 1995-1996. OH showed a robust correlation with solar zenith angle, however, beyond this dependence, HO_x ($OH + HO_2$) only showed a weak response to variations in its source and sink species. One important exception to this result was found in regions with very low O_3, nitric oxide (NO), and NO_y, where OH is highly suppressed, pointing to the critical role of NO in sustaining OH concentrations in the TTL.

Using the SCOUT-O3 and TWP-ICE campaigns conducted out of Darwin, Australia, in 2005/2006, **Robyn Schofield** showed a comparison between convection permitting versions of the WRF model and 3-hourly ERA-Interim data. She discussed the implications of global and mesoscale representations of deep convective mass fluxes and detrainment rates on the delivery of boundary layer air rich in short-lived sulfur species to the TTL and ultimately the stratosphere.

Anke Roiger presented a comprehensive SO_2 data set derived from aircraft-borne measurements carried out during a series of field experiments during the past 10 years over a broad range of latitude and altitude. She presented results from the Asian monsoon outflow region that clearly show enhanced levels of SO_2 associated with enhanced CO and ozone.

Dan Murphy summarized observations of the composition of stratospheric aerosol particles with an emphasis on PALMS (Particle Analysis by Laser Mass Spectrometry) measurements. He found that most accumulation mode particles are either organic sulfate mixtures from the troposphere or sulfuric acid particles formed in the stratosphere. A large fraction of particles are not pure sulfuric acid but contain solid inclusions (*e.g.*, meteoritic material or salts) or dissolved impurities. Aerosol of high organic content is likely to be solid, which has subsequent implications for their scattering phase function and optical detection. Black carbon was found to be only a trace constituent.

Narcisa Banda showed that observed methane (CH_4) concentration fluctuations in the years following the Pinatubo eruption were in part due to changes in OH production. She showed that the direct chemical effect of SO_2 emitted by Pinatubo decreased global OH by less than 1%, but changes due to scattering by the enhanced stratospheric aerosol caused a 3% global decrease with some larger regional effects. As a result, she found that the Pinatubo event decreased the CH_4 sink by a total of 8Tg in the first six months after the eruption.

Simone Tilmes investigated the hydrological impact of enhancing Earth's albedo by solar radiation management using simulations from 12 Earth System models contributing to the Geoengineering Model Intercomparison Project (GeoMIP). In contrast to the $4xCO_2$ experiment, where the frequency of months with heavy precipitation intensity increased by over 50% in comparison to the control experiment, a reduction of up to 20% is simulated if solar irradiance is introduced to counteract the radiative forcing from a quadrupling of CO_2. These changes in precipitation in both total amount and frequency of extremes, point to a considerable weakening of the hydrological cycle in a geo-engineered world.

Ulrike Niemeier showed results that aim to determine an upper limit of the SO_2 injection rate where balancing radiative forcing of greenhouse gases with geo-engineering is no longer reasonable. Using the global aerosol model MAECHAM5/HAM, she showed results from a set of geo-engineering scenarios with different emission strengths and heights of SO_2 injection. The results show a dependency of both microphysical parameters and stratospheric dynamics on the prescribed emission scenarios. The results also differ strongly between different microphysical models, emphasizing the need for a model intercomparison study.

Jason English used a sectional aerosol microphysical model coupled to the WACCM/CARMA model, including van der Waals forces in the coagulation scheme, to study evolving aerosol size distributions after three large eruptions ranging in size from Pinatubo to Toba. The Pinatubo simulations capture the observed peaks in aerosol loading in the Northern Hemisphere but decline too quickly and are too low in the Southern Hemisphere, possibly due to the lack of aerosol-induced heating and quasi-biennial oscillation (QBO) in the model. He found that large eruptions have self-limiting radiative effects due to increased particle size, in agreement with earlier studies.

Microphysics and climate

While volcanic eruptions have been suggested as innocuous examples of stratospheric aerosol cooling the planet, **Alan Robock** argued that the volcano analogue actually argues against geo-engineering because of ozone depletion and regional hydrologic responses. The on-going GeoMIP model simulations with standard stratospheric aerosol injection scenarios have already shown that if we could counteract increasing greenhouse gas concentrations by reducing incoming solar radiation we could keep the global average temperature constant but global average precipitation would simultaneously be reduced. He concluded that efforts to reduce anthropogenic emissions and to adapt to climate change are a much better way to channel our resources to address anthropogenic global warming.

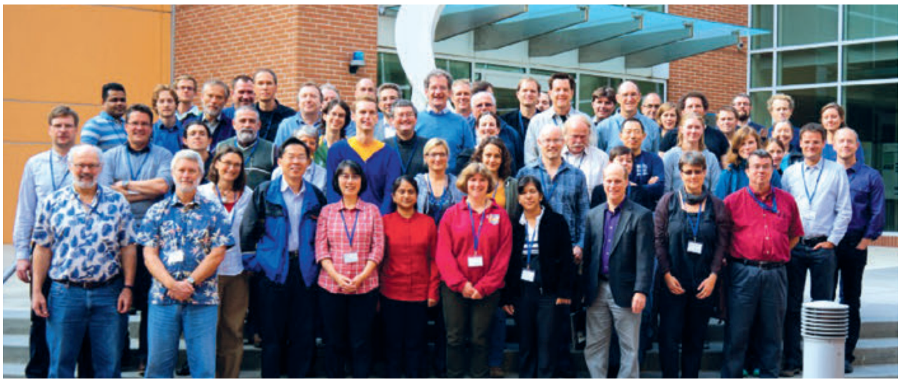

Figure 8: Participants at the SSiRC Workshop held in Atlanta, Georgia, USA.

Mike Mills reported on the development of alternative prognostic representations of stratospheric sulfate aerosol based on emissions from volcanic, anthropogenic, and other sources in the CESM1 model. He compared model simulations of the 1991 eruption of Pinatubo with observed perturbations to surface and stratospheric temperatures. This methodology will be applied to future GeoMIP studies.

Matt Toohey sought to explain why climate models generally do not capture the expected dynamical response to volcanic forcing at the surface or in the polar stratosphere. Using four different Pinatubo data sets in the MPI-ESM, he found that while tropical stratospheric temperatures are similarly affected in all experiments, significant differences in upward wave activity are apparent and led to significant differences in winter vortex dynamics. These results suggested that accurate aerosol forcing fields are necessary to improve predictions of the dynamical response to stratospheric aerosol loading.

Ross Salawitch suggested that major volcanic eruptions may have a considerably smaller influence on global climate than commonly thought. He showed that neglecting variations in the strength of the Atlantic Meridional Overturning Circulation on global temperature has led the climate community to overestimate surface cooling that results from the injection of sulfate to the stratosphere, perhaps by as much as a factor of two. He concluded that a recalibration may be needed for the proper use of past volcanic eruptions as a proxy for geo-engineering.

Jim Haywood discussed the possible role that sporadic volcanic eruptions in the Northern Hemisphere may play in Sahelian drought. He showed that three of the four driest Sahelian summers were preceded by substantial Northern Hemisphere volcanic eruptions. Model simulations show that large asymmetric stratospheric aerosol loadings concentrated in the Northern Hemisphere are a harbinger of Sahelian drought whereas those concentrated in the Southern Hemisphere induce a greening of the Sahel. These results highlight another concern regarding potential geo-engineering schemes.

Using the UKCA model including an aerosol microphysics module coupled to a stratospheric chemistry scheme, **Graham Mann** presented results showing the evolution of stratospheric aerosol through the Pinatubo period, and quantified the associated perturbation to top-of-atmosphere radiative fluxes. Results were compared to a variety of *in* *situ* and space-based observations.

Thomas Peter reported on an effort to understand why models produce shorter aerosol residence times than observed. Using the SOCOL model, which includes a comprehensive sulfur chemistry scheme and an aerosol microphysics module (AER), they found that lower coagulation efficiency was key to allowing large particles which sediment rapidly to form more slowly under stratospheric conditions. Following this approach, model simulations better matched observations and had a longer residence time than found in previous studies.

Debra Weisenstein compared and evaluated two 3D models with stratospheric chemistry and aerosol microphysics. Also using the SOCOL model, she showed that the simulated OCS and SO_2 fields compare well with observations and the background stratospheric aerosol is quite well represented, although extinction at 1.02mm was overestimated. The GEOS-Chem extension into the stratosphere shows promising results using a bulk sulfate model, but the Advanced Particle Microphysics module is yet to be implemented.

Satellite observations show that the tropical stratospheric aerosol loading is heavily influenced by QBO-induced anomalies in vertical velocity. **René Hommel** showed by means of a global aerosol model that this was particularly true in the region where aerosols evaporate. As a result, the morphology of the stratospheric aerosol layer is modulated by changes in the phase of the QBO.

Patrick Campbell addressed the global extent and variability of mid-stratospheric (>20km) condensation nuclei layer, using the CESM model coupled to a sectional aerosol microphysical code configured for pure sulfate formation in the stratosphere. The model adequately reproduces the observed layer of small particles originating in the polar stratosphere but suggests greater longitudinal symmetry and latitudinal extent in the Southern Hemisphere than in the Northern Hemisphere.

Using chemistry-climate model simulations, **Christoph Bruehl** demonstrated that the oxidation of carbonyl sulfide (COS) and volcanic injections of SO_2 into the stratosphere control the formation of stratospheric aerosol while anthropogenic SO_2 emissions play only a minor role. The calculated forcing attributed to stratospheric background aerosol is less than $0.1 W/m^2$ for the global average, while Pinatubo exerted a forcing of about $6 W/m^2$.

Summary of breakout groups and plenary discussions

Satellite and airborne field

Thomas Peter and **Larry Thomason** led a discussion of what has changed since the SPARC Assessment of Stratospheric Aerosol Processes (ASAP). One key point brought out in **Terry Deshler**'s talk is that the long-standing differences between the OPC and SAGE-II aerosol parameters, which were particularly acute during low aerosol periods, have been substantially reduced. Another issue brought up was how much the space-based component of stratospheric aerosol observations has changed since the release of the ASAP report. Until 2006 stratospheric aerosol was primarily measured using solar occultation techniques (*e.g.* SAGE); while after this period observations have primarily been made by space-based lidar (CALIPSO) and limb scattering (*e.g.* OSIRIS). It is not totally clear yet how this transition might affect the long-term time series.

Ross Salawitch discussed three recent field campaigns that were based in Guam: the Airborne Tropical TRopopause EXperiment (ATTREX), CONvective TRansport of Active Species in the Tropics (CONTRAST), and Coordinated Airborne Studies in the Tropics (CAST). All three missions are aimed at improving the understanding of the TTL and tropical western Pacific (TWP) during boreal winter. This region has the most extensive deep convective clouds and stratospheric humidity is controlled by processes at the TWP cold point tropopause where the overall chemical environment is not well characterized. The campaigns focused on the stratospheric transport of very short-lived species (VSLS) and the tropospheric fate of VSLSs.

Capacity Data Base

Marc von Hobe discussed the status of the SSiRC wiki-website featuring a collection of links to stratospheric-sulfur relevant laboratory measurements and *in situ* and remote sensing data sets from ground-based, aircraft, balloon, and satellite platforms. In addition, links to representative model output will be listed. These data sets will provide the basis for detailed process-studies and climate model validation within the framework of SSiRC and may foster extensive data intercomparisons. A close link will be maintained with the SPARC Data Initiative.

Google-X Loon

The Google-X Loon project contacted Terry Deshler to determine if a synergy was possible between the Loon balloon platforms and useful atmospheric measurements. This opportunity was discussed at the SSiRC workshop and a list of possible Loon measurements options was assembled. Terry was invited to join the Loon project's scientific advisory board, and has since facilitated contacts between Loon personnel and interested scientists. Most recently, discussions between Loon engineers and Albert Hertzog, related to improving the Loon *in situ* temperature measurements have begun.

Model intercomparison

The SSiRC climate model community met to discuss the possibilities of some common model experiments to understand the impact of stratospheric aerosol on the radiative and chemical processes controlling climate and to assess aerosol parameterization uncertainty. **Claudia Timmreck** gave an introductory talk and led the discussions, emphasizing that the need for a new model intercomparison since various new measurements of stratospheric aerosol and aerosol precursor gases have become available. She also highlighted the fact that an interactive stratospheric aerosol layer is required in climate models for more realistic simulations. After some lively discussions, the SSiRC climate model initiative, consisting of 12 different modelling groups, agreed on performing three model experiments: (1) a control simulation to understand the sources and sinks of stratospheric background aerosol, (2) a case study to evaluate a Pinatubo-like perturbation to stratospheric aerosol properties and radiative forcings across atmosphere-only general circulation models with prognostic stratospheric aerosol modules, and (3) a transient run for the last decade (2000-2010), to address the open questions of the observed increase in stratospheric background aerosol and possible links to the warming hiatus. Close collaboration with GEOMIP and AeroCom is envisaged.

Final Notes

A brief SSiRC Science Steering Group (SSG) meeting was held just after the workshop. At this meeting, the SSG decided to move forward with the organisation of an AGU Chapman Conference to be held in early 2016 and scheduled a follow-up meeting of the SSiRC SSG in Bern, Switzerland, in September 2014 where steps toward a review paper on sulfur in the stratosphere will also be initiated.

Finally, the conveners would like to express their thanks to the SPARC Office who provided substantial support, making it possible for a number of scientists to attend this SSiRC workshop, particularly students, post-doctoral scientists, and scientists from developing countries.

IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2014 Science Workshop

Michaela I. Hegglin[1], Jean-François Lamarque[2], Veronika Eyring[3], Peter Hess[4], Paul J. Young[5], Arlene M. Fiore[6], Gunnar Myhre[7], Tatsuya Nagashima[8], Thomas Ryerson[9,10], Theodore G. Shepherd[1], and Darryn W. Waugh[11]

[1]Department of Meteorology, Reading University, UK, **m.i.hegglin@reading.ac.uk**, [2]Atmospheric Chemistry Division and Climate and Global Dynamics Division, NCAR, Boulder, CO, USA, [3]Institut für Physik der Atmosphäre, Deutsches Zentrum für Luft- und Raumfahrt, Oberpfaffenhofen, Germany, [4]Cornell University, Ithaca, NY, USA, [5]Lancaster Environment Centre, University of Lancaster, Lancaster, UK, [6]Geophysical Fluid Dynamics Laboratory, NOAA, Princeton, NJ, USA, [7]Center for International Climate and Environmental Research Oslo, Oslo, Norway, [8]National Institute for Environmental Studies, Tsukuba-shi, Ibaraki, Japan, [9]Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, CO, USA, [10]Chemical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, CO, USA, [11]Department of Earth and Planetary Sciences, Johns Hopkins University, Baltimore, MD, USA

The 2014 IGAC/SPARC Chemistry-Climate Model Initiative (CCMI, **http://www.met.reading.ac.uk/ccmi/**) Science Workshop was held at Lancaster University, UK, from 20-22 May with over 130 participants (**Figure 9**). The Workshop was followed by a Scientific Steering Committee (SSC) meeting. CCMI grew out of the need to better coordinate activities that focus on chemistry-aerosol-climate interactions in the coupled stratosphere-troposphere system, assessing the science in terms of comprehensive models with chemistry. To this end, the CCMI workshop brought together experts in the development, use, and analysis of global stratosphere- and troposphere-resolving chemistry-climate models (CCMs), some including aerosols, as well as experts in both *in situ* and remote sensing observations of short- and long-lived chemical species and aerosols. Science topics included new examples of process-oriented CCM evaluation, key observations needed for model evaluation, critical topics in tropospheric and stratospheric chemistry and dynamics, as well as stratosphere-troposphere coupling.

The first morning started with a session 'CCMI - quo vadis?' The goals of the workshop were presented by the CCMI co-chairs, **Michaela Hegglin** (new CCMI co-chair) and **Jean-François Lamarque**. An overview of the 2014 WMO/UNEP Ozone Assessment by **John Pyle** emphasized the need for future contributions from CCMI to help solve open science questions related to the coupling between climate and stratospheric ozone. A presentation on the initial Coupled Model Intercomparison Project phase 6 (CMIP6) design (Meehl *et al.*, 2014) by **Veronika Eyring** (former CCMI co-chair and now chair of the CMIP Panel) laid out possible important contributions from CCMI to CMIP6, including the need for CCMI to provide chemical forcings for CMIP6 models without interactive chemistry. In addition, open questions in chemistry-climate coupling with focus on tropospheric chemistry towards IPCC AR6 were discussed by **Michael Prather**, while **Michael Schulz** highlighted potential synergies between CCMI and AeroCom (Aerosol Comparison between Observations and Models).

The opening session was followed by 1.5 days of scientific talks, discussions, and poster presentations focusing on scientific analysis of the CCMI Phase 1 simulations, which are centred on understanding the trends and interannual variability of tropospheric and stratospheric composition over the past and into the future, as well as how the composition and physical climate interact (Eyring *et al.*, 2013). The programme also included short presentations from most of the 23 modelling groups participating in CCMI. Each presentation by a model group provided an overview of the current status of the simulations and scientific highlights. Several groups have completed the global chemistry climate reference simulations, including the hindcast simulations REF-C1 (1960-2010) and REF-C1SD (with specified dynamics, 1980-2010), and the recent-past to future simulation REF-C2 (1960-2100, using the RCP6.0 scenario beyond 2005). Several groups have also performed a number of the proposed sensitivity simulations. Additional groups with tropospheric-oriented, stratospheric-oriented, or fully coupled models are encouraged to participate in this ongoing set of coordinated simulations.

Figure 9: The 130 participants of the 2014 CCMI Science Workshop at Lancaster Castle (the green grass is fake, but the blue sky is not).

A session on 'Novel observations to test model performance' included talks on stratospheric and tropospheric satellite data, and recent aircraft measurement campaigns in the tropical pacific region: Airborne Tropical TRopopause EXperiment (ATTREX), CONvective TRansport of Active Species in the Tropics (CONTRAST), and Co-ordinated Airborne Studies in the Tropics (CAST). 'Hindcast simulations and proposed evaluations' focused on various methodologies to evaluate the CCMI hindcast simulations, including using the long-term tropospheric ozone record, the record of total column ozone, aerosol trends, idealized tracers, and satellite carbon monoxide measurements. The session on 'Process oriented model evaluation: dynamics, transport, and chemistry' emphasized methodologies that can be used to better diagnose model processes. Talks covered topics including the emissions of natural aerosols, the diagnosis of hydroxyl differences between models, the impact of dry deposition parameterizations for ozone, the impact of gravity wave parameterizations on Antarctic ozone loss, and how CCMI analyses might take advantage of the Global Atmosphere Watch (GAW), Network for the Detection of Atmospheric Composition Change (NDACC) and Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN) observation networks. The final science presentation session was called 'Linking model performance to future projections: dynamics, transport, and chemistry', including talks that considered the influence of chemistry-climate feedbacks when making climate projections, the importance of accounting for long-term natural variability in model analysis, projections of future stratospheric variability in the Arctic, future changes in stratosphere-troposphere coupling and ozone, and the impact of short lived bromocarbons on ozone recovery. Many of the talks and posters have been uploaded to the workshop website (**http://www.lancaster.ac.uk/ccmi2014/agenda**).

On the last day of the workshop the participants were split into five breakout groups, which were all given the task of discussing the same topics: (1) CCMI objectives, and potential links with the aerosol community or the wider climate modelling community, (2) routine benchmarking for CCMI models, and (3) definition of simulations and scenario runs within CCMI. Items arising from the group discussions were subsequently presented in plenary to stimulate further discussion, with the goal of defining the way ahead for CCMI. The workshop then closed with a meeting of the CCMI SSC.

Major outcomes of the discussions during the workshop and the SSC meeting are outlined in the following. In order to connect to the aerosol and climate modelling communities (discussion topic 1), CCMI will take the responsibility of providing the CMIP modelling community with updated forcings, including ozone, stratospheric aerosol, and nitrogen deposition data sets. Support for the Global Emissions InitiAtive (GEIA) efforts to create new emission databases is envisaged through testing their derived emission data sets in CCMI models. CCMI will also establish close links with AeroCom and will submit a joint 'AerChemMIP' proposal for a CMIP6-endorsed model intercomparison project. This will encompass the parts of both projects that relate to CMIP6, emphasizing that the interaction between chemistry and aerosols is important in quantifying their climate forcing.

Important outcomes from CCMI science will be the routine benchmarking of CCMs and ESMs (discussion topic 2). CCMI will need to define which evaluations should be considered routine evaluation (*i.e.*, well-established and documented diagnostics), and could serve as the starting point for evaluations of each new model simulation. It is envisaged that the diagnostics and performance metrics identified for routine evaluation will be implemented into the ESMValTool (which supersedes the previously developed CCMVal diagnostic tool). These diagnostics will help to build tools to evaluate and further develop models in anticipation of CMIP6 and CCMI Phase 2 (CCMI-2). In this context,

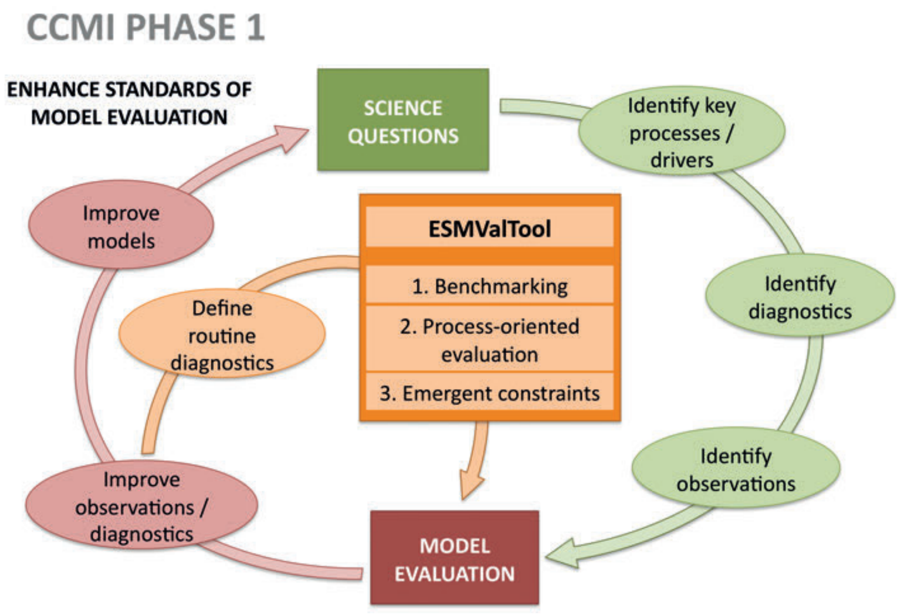

Figure 10: CCMI Phase 1 science approach. The goal of CCMI-1 is to improve the standards of model evaluation in both the stratosphere and the troposphere, but also for the stratosphere-troposphere coupled system. Science questions should drive the design of process-oriented diagnostics. While tropospheric diagnostics still need to be explored (green phase), many stratospheric diagnostics already exist and need to be refined for inclusion into the ESMValTool (orange phase).

CCMI also decided to contribute to the submission of data to the Obs4MIPs initiative (Teixeira *et al.*, 2014).

Finally, it was recognized that over the next year most modelling groups would focus on performing the reference simulations (discussion topic 3). In particular, simulations of future conditions will not be of high priority, noting that there will be new scenarios developed for CMIP6 possibly more appropriate for CCMI than the RCPs. These will span a broader range of possible future developments for aerosol and short-lived species, and will also enable the simulations to address specific policy-relevant questions (*e.g.*, the impact of short-lived climate forcers, regional responses to specific forcing agents, *etc.*).

Summary

- The main focus of CCMI Phase 1 (CCMI-1) remains the exploration and application of new process-oriented diagnostics and emergent constraints using the hindcast (REF-C1 and REF-C1SD runs), and the REF-C2 simulations (see green phase in **Figure 10**). A full list of the currently proposed diagnostics and analyses can be found at **http://www.met.reading.ac.uk/ccmi/?page_id=23**.
- A set of key diagnostics including constraints derived from observations will be identified and refined in a manner that they become suitable for implementation into the ESMValTool (see orange phase in Figure 10).
- The deadline for submission of model data to the CCMI data archive at the British

Atmospheric Data Centre (BADC) is December 2014. The option of uploading data to existing Earth System Grid Federation nodes is also available until then. Data analysts are encouraged to use all model data available by this deadline for their CCMI evaluations. However, model data submitted later than December 2014 should also be included in the evaluations wherever possible.

- A combined special issue in Atmospheric Measurement Techniques/Atmospheric Chemistry and Physics/Geoscientific Model Development will be initiated aiming for a collection of papers on scientific analysis of the CCMI-1 simulations, with a start date of May 2015. It is encouraged to submit multi-model CCMI analyses as well as single model studies, which serve as proof-of-concept for the use of new observations or process-oriented diagnostics in model evaluation.
- The next CCMI workshop will likely be held in autumn 2015, with a one-day overlap with the AeroCom annual science meeting to allow for discussion and coordination of AerChemMIP.

More details about the workshop, including presentations, can be found on the workshop website at **http://www.lancaster.ac.uk/ccmi2014**. A CCMI science plan including a stratosphere-troposphere evaluation diagnostic table (extended from Eyring *et al.*, 2005), will be published in due time and announced on the CCMI website.

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SPARC meetings

27-29 August
Polar Stratospheric Clouds Workshop, Zurich, Switzerland

8-12 September
Joint S-RIP/Data Assimilation Workshop, Maryland, USA

22-26 September
SSiRC Scientific Steering Group Meeting, Bern, Switzerland

New SPARC publications

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40^{th} Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events: COS-MOS, Moscow, Russia

16-21 August
World Weather Open Science Conference WWOSC-2014, Montreal, Canada

23-28 August
SCAR 2014 Open Science Conference, Auckland, New Zealand

22-26 September
13^{th} IGAC Science Conference / 13 Quadrennial iCACGP Symposium, Natal, Brazil

6-10 October
14^{th} European Meteorological Society (EMS) Annual Meeting & 10^{th} European Conference on Applied Climatology (ECAC), Prague, Czech Republic

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Publication details

Editing
Fiona Tummon

Design/layout
Carolin Arndt

Print & distribution
ETH Zurich

ISSN 1245-4680

SPARC Office

Director
Johannes Staehelin
Project Scientists
Fiona Tummon
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Petra Bratfisch

Contact
SPARC Office
c/o ETH Zurich
Institute for Atmospheric and Climate Science (IAC)
Universitaetstrasse 16
CH-8092 Zurich
Switzerland
office@sparc-climate.org