SPARC

Stratosphere-troposphere Processes And their Role in Climate

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Gravity waves in irridescent cirrus clouds above a tropical thunderstorm seen above Bangkok, Thailand, during the 2nd ACAM workshop (see report this issue). Photo courtesy: Guy Brasseur.

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Report on the 23rd SPARC Scientific Steering Group Meeting
10-13 November 2015, Boulder, Colorado, USA

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The 23rd session of the SPARC Scientific Steering Group (SSG) was held at the National Center for Atmospheric Research (NCAR) in Boulder, USA, from 10-13 November 2015. The meeting was opened by Joan Alexander, SSG co-chair, who read out a message from Guy Brasseur, chair of the WCRP Joint Steering Committee (JSC), who was unable to attend the meeting.

WCRP news and Grand Challenges

The WCRP (**Boram Lee**, SPARC liaison) remains committed to supporting innovative research, which is vital to ensuring that climate information produced for society is credible. WCRP is working ever more closely with the World Weather Research Programme (WWRP), as weather and climate science overlap to an ever greater extent. There is a critical need for these sorts of partnerships to ensure that limited resources are used in a synergistic way to make a larger impact. WCRP's regional presence has been most strongly advocated by the CORDEX project, which has recently launched a call for "Flagship Pilot Studies". In tandem with this, the Working Group on Regional Climate (WGRC) will be launching their first "Frontier Projects" in 2016. These projects will serve as an initial proof-of-concept and are aimed at proving how regional climate information is useful in particular contexts. On a broader scale, WCRP capacity development efforts are aimed at empowering long-term achievements in climate research by continuously advocating for data and knowledge sharing, investing in early career researchers, and supporting sustainable bottom-up organised global and regional research activities.

Two new WCRP Grand Challenges have been proposed (**Yochanan Kushnir**, **Neil Harris**). The first, focused on "Near-term Climate Prediction", aims to issue real-time global five- to ten-year climate outlooks based on initialized model predictions, thereby improving the products provided by climate services globally. Three main topics have been identified that will leverage on-going research: Understanding uncertainty in decadal predictions, validating model predictions, and communicating these predictions along with their associated uncertainties. There will also be focus on particular scientific issues, such as solar forcing, volcanoes, anthropogenic aerosols, and ozone, among others, to which SPARC could contribute significantly. The second Grand Challenge will concentrate on "Biogeochemical cycles and climate change", with a main focus on the carbon cycle. This Grand Challenge is not intending to consider short-lived climate forcers (SLCFs) such as aerosols, and thus it was proposed that SPARC consider a new activity focusing on these species as a complement to this Grand Challenge. Both Grand Challenges will be presented at the next WCRP JSC Meeting scheduled for April 2016.

SPARC activity updates

The joint SPARC-IGAC Atmospheric Composition in the Asian Monsoon (ACAM) activity has continued to build a regional community around their main research topics: emissions and air quality in the Asian monsoon region; aerosols, clouds, and their interactions; the impact of monsoon convection on chemistry; and the upper troposphere/lower stratosphere (UTLS) response to the Asian monsoon (**Laura Pan**). A highlight of 2015 was the 2nd ACAM workshop held in Bangkok, Thailand, in June, which had a much broader representation of countries from the region than the 1st workshop held in 2013. In conjunction with this workshop, the first ACAM training school on 'Satellite and model data use for aerosols and air quality' was held for a group of early career researchers participating in the main workshop. An upcoming workshop on the UTLS and the Asian Monsoon is being organised in Boulder, USA, from 7-11 March 2016.

The second joint SPARC-IGAC activity, the Chemistry-Climate

Model Initiative (CCMI), made good progress during 2015 on a number of fronts (**Michaela Hegglin**). Models continue to be improved and data from many of the participating modelling groups are now available on the BADC (British Atmospheric Data Centre) as well as the ESGF (Earth System Grid Federation). A CCMI joint special issue in the EGU journals (ACP/AMT/GMD/ESSD) has been established and will open in early 2016. The group is also very involved in CMIP6 through the AerChemMIP project, jointly developed with AEROCOM, as well as producing an updated ozone forcing dataset for models without interactive chemistry. CCMI's next workshop is planned for early 2017 however they are hoping to have a large presence at the IGAC 2016 Conference to be held in Breckenridge, USA, from 26-30 September.

The SPARC Data Assimilation Working Group (DAWG) again held a joint workshop with S-RIP in 2015 (**Quentin Errera**). The workshop focused on three themes: added value of chemical data assimilation, bias correction and harmonisation of datasets, and the representation of the stratosphere and mesosphere in models and reanalyses. Results from the new MERRA-2 reanalysis were presented, as well as a preview of the ERA-5 reanalysis which is planned for release in 2016 or early 2017. The latter model includes 137 vertical levels and has an improved gravity wave scheme which results in a significantly better quasi-biennial oscillation (QBO). The group is again planning a joint workshop for 2016, to be held in Victoria, Canada from 17-19 October.

Similar to CCMI, the Dynamical Variability activity (DynVar) has been involved with the developments of CMIP6 (**Ed Gerber**). The group has established a diagnostic model intercomparison project (MIP), which is focused on ensuring that the right model output is archived to allow a proper diagnosis of processes related to stratosphere-troposphere coupling, the atmospheric momentum budget, and parameterised processes such as gravity waves and the planetary boundary layer. It is hoped that results from this MIP, and from the other MIPs with which DynVar is connected, will help modelling centres address certain persistent model biases. DynVar is organising a workshop to be held in Helsinki, Finland, from 6-10 June 2016.

The Stratospheric Network for the Assessment of Predictability (SNAP) completed one of their main experiments during 2015 (**Andrew Charlton-Perez**). This model experiment used operational forecasts of sudden stratospheric warmings (SSW) to investigate whether these events improve predictability in the Northern Hemisphere. They have published two papers on these results, and are hoping to submit a third about new results looking into a final warming event in the Southern Hemisphere. The group is very involved in the joint WCRP-WWRP sub-seasonal to seasonal (S2S) project and plan analyses of this project's archive of simulations as they evolve their focus to look more at the impacts of stratospheric predictability on tropospheric variability and the sub-seasonal forecasting timescale (see also p.11, this newsletter).

New studies from the Gravity Waves activity have shown that global models at very high horizontal and vertical resolution can produce relatively realistic gravity waves at a range of scales even without a gravity wave parameterisation (**Joan Alexander**). However, not many models can be used at these high resolutions and even the best models don't simulate the entire range of gravity waves well. Parameterizations represent common small-amplitude waves but omit the uncommon large-amplitude waves that primarily drive the stratospheric circulation. These issues will be among the topics discussed at the upcoming SPARC Gravity Wave Symposium to be held from 16-20 May 2016 in Pennsylvania, USA, as well as the International Conference on the Whole Atmosphere to be held from 14-16 September 2016 in Tokyo, Japan.

The Solar Influences for SPARC (SOLARIS-HEPPA) activity published a series of papers in 2015 looking at the solar cycle in CMIP5 simulations (**Katja Matthes**). They found that much of the spread between models was related to how they represented ozone, with some having interactive ozone, others using the CMIP5 specified ozone, and some models with no ozone at all. It will be vital for CMIP6 that models include ozone, even if not interactively. The group will continue to study the solar cycle in models, in particular in the CCMI simulations, considering also various statistical approaches together with statisticians. A major focus of the activity is also producing the CMIP6 solar forcing, which will cover both the historical (1850-2014) and two future scenarios (2014-2300). They are planning the 6th SOLARIS-HEPPA workshop in Helsinki, Finland, in June 2016.

During 2015 the Stratospheric Sulfur and its Role in Climate (SSiRC) activity worked particularly on the analysis and observations side

(**Terry Deshler**). A database that is part of a SSiRC wikipage has been developed and includes a wide variety of observations, including several old lidar data, which they are in the process of rescuing. The group recently submitted a review paper on stratospheric aerosols and is working on various further publications, including one on estimates of the sulfur burden from observations. The first sonde measurements of the StratoClim field campaign were made in 2015 in Saudi Arabia and India, and the continuation of this campaign (including aircraft as well as ground-based measurements) will be a major focus of the group in 2016. Emphasis will also be on the SSiRC model intercomparison project, which will be continued and analysed in depth during 2016. Both these topics will be further discussed at the 2nd SSiRC workshop to be held in Potsdam, Germany, from 25-28 April 2016. Finally, a new Principal Investigator at the University of Colorado has been found, so it is hoped that the *in situ* record of stratospheric aerosol that started in Wyoming in 1971 will be continued from Boulder.

The Water Vapour Assessment (WAVAS-II) activity made significant progress on their satellite observations report (**Karen Rosenlof**). A significant component of this report is dedicated to comparing satellite water vapour observations with ground-based measurements. It also covers comparisons of derived quantities, for example, the tropical tape recorder and also includes some of the first analyses of water isotope observations from satellites. The report will provide one of the last major stratospheric water vapour reviews that can be done for the foreseeable future. They are aiming to finalise it by the end of 2016.

The SPARC Reanalysis Intercomparison Project (S-RIP) spent much of 2015 putting together the first chapters of the S-RIP report (**Sean Davis**). These chapters will focus on providing an overview of reanalyses as well as climatologies of dynamical variables, ozone, and water vapour, and will form the basis of an interim report to be published digitally in 2016. The group put considerable effort into converting data from the nine different reanalyses they are considering into a common format. These data have been included in the Ana4MIPs database and are available to the community. Two new co-leads for the activity have been elected: Gloria Manney and Lesley Gray, who will serve alongside Masatomo Fujiwara. Together with DAWG (see above) they are planning the 4th S-RIP workshop to be held in Victoria, Canada, from 19-21 October 2016.

The temperature trends activity held a workshop in April in Victoria, Canada, with much discussion about the future of the activity (**Andrea Steiner** and **Amanda Maycock**). There was strong consensus among participants and support for a continuation of the activity with new foci, including better understanding temperature variability, trends and uncertainty in climate records, and the role of composition in observed temperature changes. The group has already started looking into novel observational records, such as GPS radio occultation and GRUAN radiosonde observations, and will use these new datasets to continue previous work evaluating the consistency of atmospheric temperature records among observations, reanalyses, and models. The new focus of the activity, which has adapted its name to 'Atmospheric Temperature Changes', will be further discussed at a workshop to be held from 25-26 April 2016 in Graz, Austria.

Emerging activities

The Polar Stratospheric Clouds initiative (PSCi) developed from a workshop held in August 2014 (**Michael Pitts**). Since then, the group was successful in obtaining support through the International Space Science Institute (ISSI) for three meetings, one of which was held in October 2015 in Bern, Switzerland. The main aims of the initiative are to produce several reference data sets for different aspects of PSCs using both satellite and *in situ* observations. Most of this work is to be completed during 2016 and will be discussed at the second ISSI meeting planned for late 2016. They will work together with modellers to ensure that the datasets produced are easily accessible and useful for model validation. The final ISSI meeting will likely focus on a review paper in 2017, which hopefully will be finalised in time for the 2018 WMO/UNEP Ozone Assessment.

The Quasi-Biennial Oscillation initiative (QBOi) held their first workshop in March 2015 in Victoria, Canada, where the group decided on the model experiments to be carried out by participating modelling teams (see SPARC Newsletter July 2015) (**Scott Osprey**). They also carried out an assessment of how models and reanalyses currently simulate the QBO, with much more spread between models than reanalyses. The model QBOs generally did not extend down into the lowermost stratosphere as observed, and they weren't able to capture the rapid shifts between east and west QBO phases. Where these biases originate from and how they can be reduced are open questions that the initiative is hoping to address.

Ultimately, they would like to be able to understand how sensitive various teleconnections are to simulated QBO biases.

The activity focused on 'Solving the Carbon Tetrachloride mystery' has worked in earnest during 2015 to better understand the reported gap between top-down (satellite inversion techniques) and bottom-up (inventory-based) estimates of carbon tetrachloride (CCl_4) emissions (**Paul Newman**). The slower than expected decrease in atmospheric levels of CCl_4 has led to questions about reported emissions and the estimated lifetime of this species, which is controlled by the Montreal Protocol. A workshop held in Zurich, Switzerland, in October 2015 brought a wide range of experts together and went some way to solving the CCl_4 'mystery'. The group is working to produce a SPARC report for release in the first half of 2016.

The three emerging activities, PSCi, QBOi, and CCl_4, were all accepted as full SPARC activities. Andrea Steiner and Amanda Maycock were approved as new co-leads of the Atmospheric Temperature Changes activity, while Lesley Gray and Gloria Manney were approved as co-leads with Masatomo Fujiwara of S-RIP. SPARC thanks Dian Seidel, Bill Randel, and Dave Thompson for leading the Temperature Trends activity so successfully over the past years.

Proposed new activities

On behalf of Marv Geller, **Kaoru Sato** presented a proposal for a new SPARC activity on FIne-Scale Atmospheric structures and ProcesseS (FISAPS), which grew out of an effort to collect high-resolution radiosonde data from a number of countries. These data provide an excellent opportunity to investigate a wide range of processes in the atmosphere since the 10-20m vertical resolution of these data can easily be used to consider features at scales smaller than 1km. The data could potentially be used to look at processes such as the emission of gravity waves near mid-latitude jets, as well as other fine-scale structures near the tropopause and in the planetary boundary layer. The activity would aim to encourage other nations to provide the high-resolution radiosonde data, which are routinely measured but not often archived or distributed. It is hoped that several southeast Asian countries will contribute data as part of the Years of the Maritime Continent field campaign (scheduled for 2017-2019).

Seok-Woo Son reported on an international workshop on 'Stratosphere-troposphere dynamical coupling in the tropics' on behalf of Shigeo Yoden. The workshop focused both on modelling and observations, with sessions on how the QBO influences various aspects of the tropical climate (*e.g.* deep convection, Madden-Julian Oscillation), the influence of SSWs on tropical dynamics, the solar cycle in the tropics, convection and waves, as well as other related on-going activities (*e.g.* within WCRP, *etc.*). Two further workshops are planned in 2017 and 2019. A SPARC activity may develop out of this effort, particularly given the complementarity with the QBOi and the WCRP Grand Challenge on clouds, circulation, and climate sensitivity, as well as links with regional capacity development.

WCRP working groups and advisory councils

The WCRP Working Group on Coupled Modelling (WGCM; **Gerald Meehl**) recently met in conjunction with the third CMIP

Figure 1: Participants at the 23rd SSG meeting held in Boulder, CO, USA.

workshop meeting in October in Dubrovnik, Croatia. These workshops are aimed at providing an overview of the main CMIP science and have a very popular format of sessions with 20 scientists each presenting one slide for three minutes, before a half-day of poster discussions. Issues raised by modelling groups participating in CMIP5, such as too many intercomparison projects and not enough time to run experiments, have hopefully been addressed in the new framework for CMIP6. The duration of CMIP6 is planned from 2015-2020, with the hope that this will allow a more equal spread of computing and work load. This timeframe may, however, have to shift slightly given the plans for a 6^{th} IPCC assessment report, which is expected to be finished at the end of 2020. A vital aspect to the new CMIP6 structure is the inclusion of a "vulnerability, impacts, and adaptation" advisory board to ensure that there is communication with the community that frequently uses climate model output.

The Working Group on Numerical Experimentation (WGNE; **Ayrton Zadra**) was set up over 30 years ago to serve as liaison between different modelling communities within WMO and WCRP. At their 30^{th} annual meeting a number of activities of relevance to SPARC were discussed. One example is the joint WCRP-WWRP polar prediction project where there is clear connection to SPARC in terms of expertise in regional circulation. Another possible avenue for SPARC to connect with WGNE is through their 'Grey Zone' project that considers the range in resolution where convective parameterisations in models reach their limits. This project's next case study will focus on tropical regions and SPARC could get involved in this if there is interest. A workshop planned for April 2016 in Reading, UK, will consider atmospheric drag processes and their links to large-scale circulation, which links closely with the WGNE project on surface drag parameterisations as well as the SPARC gravity wave and DynVar activities.

The WCRP Model Advisory Council (WMAC) was established to coordinate modelling activities across WCRP's various modelling working groups (**Joan Alexander**). They helped organise the first WMAC climate model development summer school, entitled 'Atmospheric moist processes', which took place in Hamburg, Germany, in June 2015. Videos of the lectures from the school have been archived and will be made available for training purposes soon. The first WMAC prize for model development was also awarded this year, while nominations for 2015 were closed on 1 October with the winner to be announced in early 2016. To further encourage model development, WMAC asks all WCRP groups to consider the possibility of highlighting model development at their meetings, for example, through invited speakers or dedicated sessions. WMAC has also been active in relation to CMIP6, suggesting that entry requirements may not be convenient for all MIPs and there may need to be some room for limited flexibility for particular MIPs.

The WCRP Data Advisory Council (WDAC) is similar to WMAC but focused on observations (**Susann Tegtmeier**). At their 4^{th} meeting held in Reading, UK, in July 2015, it was noted that there was a looming gap in limb sounding observations of upper tropospheric/stratospheric composition and that a coordinated effort to advocate for such measurements was needed. WDAC also highlighted the need for a WCRP-wide common data policy, with the main focus being the promotion of open data use and the use of DOIs when possible. Complementary to WMAC, WDAC is developing a joint WCRP-GCOS data prize, which is likely to be open for nominations in 2016. There was also discussion around the upcoming GCOS conference to be held from 2-4 March 2016 in Amsterdam, Holland, where SPARC is planning to participate. Finally, WDAC has a task team putting together a white paper on the intercomparison of reanalyses in which S-RIP will feature strongly.

Updates on partner projects and programmes

Claire Granier gave an update on the IGAC (International Global Atmospheric Chemistry) project. Over the past year IGAC sponsored or endorsed about 20 workshops, meetings, and training schools, and have placed particular emphasis on reaching out to new communities, for example, air quality researchers in Asia. This links very much with their capacity development efforts, which are largely carried out by their regional working groups that are currently established in Japan, China, the Americas, and southeast Asia. In 2016 IGAC will be hosting their next biennial conference in Breckenridge, Colorado, USA, of which several sessions may be of interest to the SPARC community, including those on 'atmospheric chemistry and climate', 'observing atmospheric composition and variability', and 'fundamental studies of atmospheric chemistry'.

The Global Atmosphere Watch (GAW) has recently established a new scientific advisory group on near-real time applications, reflecting the renewed emphasis on providing information rather than just data (**Geir Braathen**). In this effort, GAW is collaborating with many groups, such as the World Health Organization (WHO) and the WMO agricultural meteorology community, to develop added-value products using GAW observations. They have also developed a new interface called GAWSIS, hosted by MeteoSwiss, which includes metadata from the entire GAW network and links to available data. In collaboration with SPARC, GAW is organising a workshop about UTLS observations from 23-27 May 2016 at WMO in Geneva, Switzerland. The workshop will focus largely on observations of ozone, water vapour, and carbon monoxide, assessing the quality of these observations from multiple instrument platforms in the UTLS region. It is possible that a new SPARC activity that looks at UTLS composition changes in a holistic way develops out of this workshop.

The Network for the Detection of Atmospheric Composition Change (NDACC) celebrated 25 years of existence in 2015 and is commemorating this with a special issue in ACP, AMT, and ESSD (**Michael Kurylo**). The network is made up of various working groups focused on particular measurement techniques. The Brewer/Dobson group has been reprocessing all records, including those from stations no longer measuring ozone, and is also evaluating a new instrument (Pandora) that could possibly replace old Dobson instruments. The FTIR group has been extending its analyses to provide profile retrievals rather than just partial columns, while the working group on UV and visible measurements has worked together with the European COPERNICUS Atmospheric Monitoring Service to validate some of their forecast products.

GEWEX (Global Energy and Water EXchanges), also a WCRP core project, has several activities where collaboration with SPARC could be further developed (**Peter van Oevelen**). These include several PRocess and Evaluation Studies (PROES), such as their activities on Upper Tropospheric Clouds and Climate (UTCC), and Mid-latitude Storms, as well as a new activity on Clouds, Convection, and Aerosols, which is currently being developed in GEWEX. There may, in particular, be overlap between the UTCC activity and the focus on UTLS observations within both SPARC and GAW, as well as between the Mid-latitude storms activity and the WCRP Grand Challenge on clouds, circulation, and climate sensitivity.

The joint SPARC-CliC Polar Climate Predictability Initiative (PCPI) has six sub-initiatives, three of which are joint with the WWRP Polar Prediction Project (PPP) (**Marilyn Raphael**). All six sub-initiatives have been very active over the past year, with several special sessions at conferences such as EGU and AGU as well as journal publications. The sub-initiative focused on improving the predictability of polar sea-ice is hosting a workshop in May 2016 about Polar Predictability together with the PPP, and will contribute to the proposed WCRP Grand Challenge on near-term climate prediction. Two further workshops possibly of interest to the SPARC community are being planned for 2016, on 'Polar feedbacks' to be held in Belgium, and in 2017, on 'Zonal asymmetry in the Southern Hemisphere' (date and place still to be determined).

Space agency updates

Anne Grete Straume presented an update from the European Space Agency (ESA), particularly focusing on the ADM-Aeolus mission, which is to be launched in March 2017. This will be the first time a Doppler lidar measuring in the UV is sent into space. The instrument will measure atmospheric winds from the surface up to an altitude of 30km in both cloud-free and cloudy conditions, producing data which will be used to improve weather forecasts as well as reanalyses. In addition to this mission, ESA has a large number of on-going and planned missions focusing on Earth system science. These include EarthCARE, focusing on aerosol-cloud-radiation interactions, the Earth Explorers, and the Sentinel series of satellites, which are largely focused on operational meteorology and air quality measurements.

NASA (US National Aeronautics and Space Administration) currently has a large number of satellites in space hosting various instruments that measure atmospheric composition (**Kenneth Jucks**). These include instruments on Aura, which is likely to continue at least another two years (with the exception of TES, which may discontinue operation at any time), as well as the OMPS instrument on-board the Suomi NPP satellite. The SAGE-III instrument will also be launched in May 2016 on the International Space Station with a planned mission length of three years, although this may be extended until 2023 if all goes well. NASA has also helped organise several workshops that have provided input for the Decadal Earth Science Survey, which is aimed at prioritising science foci for the 2017-2027 decade. Contributions to this survey have already been made by SPARC and there will be several further opportunities to do so in the coming months.

Kaoru Sato presented a brief update on the Japanese Aerospace Exploration Agency (JAXA) on behalf of Makoto Suzuki. Of particular relevance to SPARC is the SMILES-2 programme, which is currently in design. This satellite mission is the follow-up of the SMILES-1 instrument which flew on-board the international space station for several months. SMILES-2 will be a relative light satellite with a planned lifetime of five years and instruments that will measure atmospheric composition at altitudes from 35-80km. JAXA also has several other satellites in space, including GOSAT, which measures carbon dioxide and methane very precisely, as well as the GPM satellite which measures vertical profiles of precipitation rates, even distinguishing between rain and snow.

The Canadian Space Agency (CSA) currently has three missions still in space: MOPITT, OSIRIS, and SCISAT (which hosts the ACE-FTS instrument) (**Thomas Piekutowski**). The data from these missions have been widely used in a number of applications, including, for example, in assimilation products used to guide Arctic airborne campaigns. Studies are currently underway for two micro-satellite missions: CATS, a follow-up mission to OSIRIS, and TICFIRE, to focus on thin ice clouds. The CSA also has several instruments under development for airborne campaigns, which hopefully would eventually also be launched on satellite platforms. These include SHOW, which makes fast high vertical resolution observations of water vapour, and FIRR, which, similar to TICFIRE, will be used to study ice clouds.

There are no long-term satellite missions planned for the foreseeable future aimed at measuring stratospheric composition beyond ozone and water vapour (which will be measured, even if relatively sparsely, from the SAGE-III instrument to be on board the International Space Station from May 2016 onwards). A group of SPARC scientists led by **Karen Rosenlof** are working on an article addressing this upcoming 'gap' to be published in 2016. Volunteers are very welcome to contribute and asked to please contact the SPARC Office if interested.

Other SPARC items

During the final session of the meeting several organisational and strategic items were discussed. 2015 has seen much work on the new SPARC implementation plan, which has recently been finalised. Planning for the next SPARC General Assembly, to be held in Kyoto, Japan in September/October 2018, is well underway (Kaoru Sato). Teleconferences are to be organised throughout the year to encourage synergies between activities and also to promote links with related projects and programmes (*e.g.* the WCRP Grand Challenges and core projects, IGAC, *etc.*). It was also noted that it would be very helpful if papers that have developed out of WCRP and SPARC activities acknowledge this. A standard acknowledgement is now available on the SPARC website (**www.sparc-climate.org/publications**); please contact the SPARC Office if you wish to adapt this. There was quite some interest in SPARC becoming more active on social media, since this may prove an effective way to communicate SPARC science to a wider community and to engage younger researchers. Various possibilities for how this can be put into practice are being investigated. SPARC is still exploring options for a new host for the Project Office, which will be moving on from Zurich, Switzerland, at the end of 2017.

A SPARC capacity development strategy has been put together in parallel and to complement the new science implementation plan (**Fiona Tummon**). The strategy seeks to build on existing efforts in an efficient way and in collaboration with WCRP. Emphasis is on building regional capacity and supporting early career researchers. Over the past year several successful capacity development activities have happened, for example, the ACAM training school (see article p.20 this newsletter), a lunch time capacity development session at the ICHSMO 2015 conference in Santiago, Chile (see p.43 this newsletter), as well as links being built with the YESS (Young Earth System Scientists) network, which is being promoted by WCRP, WWRP, and GAW. **Seok-Woo Son** has also put significant effort into establishing a regional SPARC working group covering Asia and the Pacific. This group has ensured that SPARC is more visible at regionally focused conferences (*e.g.* AOGS and the 1st Asian conference on Meteorology). A training school was also organised from 5-8 January 2016 in Bandung, Indonesia, on tropical meteorology. Over the coming year SPARC is hoping to expand capacity development efforts further by continuing support for regional working groups and training schools, growing the SPARC group within the YESS network, and making capacity development more visible on the SPARC website.

Scientific Assessment of Ozone Depletion 2018: Meeting the needs of the Parties to the Montreal Protocol

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– To the Chemistry-Climate Modelling Communities –

Under Article 6 of the Montreal Protocol, the Scientific Assessment Panel (SAP) is tasked with providing an assessment of the state of the ozone layer every four years, under the leadership of the four Co-chairs. At the 27th Meeting of the Parties to the Montreal Protocol, Drs. David W. Fahey and Bonfils Safari succeed A.R. Ravishankara, and Ayite-Lo Ajavon upon their retirement from the SAP. Drs. Fahey, Newman, Pyle, and Safari will lead the 2018 Ozone Assessment. This written Ozone Assessment is produced under the auspices of the Montreal Protocol with the assistance of the United Nations Environmental Program's (UNEP) Ozone Secretariat, and the World Meteorological Organization (WMO).

In November 2015, the Parties to the Montreal Protocol agreed to the terms-of-reference for the "Scientific Assessment of Ozone Depletion: 2018" and requested the SAP to deliver this report by 31 December 2018. The 2018 terms are very broadly stated and encompass the terms for the previous Assessments. The topics include updates on trends and emissions of ozone depleting substances (ODS) and their substitutes, current findings on stratospheric ozone abundances and trends, future ozone projections, and new science findings related to stratospheric ozone. The Co-chairs have broadly re-formulated the terms into a series of prioritized science questions:

- How will the ozone layer change over the 21st century in response to atmospheric changes from sudden stratospheric warmings, an accelerated Brewer Dobson circulation, and other processes?
- What are the impacts of climate gases (CO_2, CH_4, N_2O, HFCs, *etc.*) on the stratospheric ozone layer? Can we de-convolve their relative effects?
- Is the Antarctic ozone hole and Arctic winter/spring ozone depletion developing according to our understanding?
- Is the recovery of ozone in the upper stratosphere consistent with our expectations based on Cl_y, temperature, and other factors?
- What is the impact of the changing stratosphere on surface climate (*e.g.*, past Antarctic and Arctic ozone depletion and future recovery)?

The above questions are not exclusive, and the terms give wide latitude for additional questions and research findings. A solicitation to the community from the SAP Co-chairs on the scope of the 2018 Assessment will be sent out in late 2016. The 2018 assessment components will be: Science Chapters, Assessment for Decision Makers (ADM), and 20 Questions and Answers (see **www.esrl.noaa.gov/csd/assessments/ozone**).

Although specific dates for the 2018 Assessment are yet to be determined, the SAP Co-chairs have initially decided to follow a timeline and structure that parallels the timeline used for the 2014 Assessment. The major events are:

- Chapter outline and author solicitation: September/October 2016
- Chapter Lead Authors named: March/April 2017
- Completion of first and second chapter drafts: September/October 2017 and April/May 2018
- Final chapter drafts, ADM, and 20 Questions and Answers content approved: June/July 2018
- ADM released: September, 2018
- Presentation of completed 2018 Assessment to the Montreal Protocol Parties: November 2018
- Full assessment available to Parties: 31 December 2018 (printed by April 2019).

The SPARC-supported chemistry-climate model (CCM) activities have been an outstanding success for analyzing and supplying model simulations for use by the Assessment chapter authors. CCMVal-1 contributed to the 2006 assessment, while CCMVal-2 contributed to the 2010 and 2014 assessments. These simulations not only showed the trajectory of ozone through the 21st century, but the models were also tested against observations to show their credibility. Results from CCM simulations will continue to provide essential input to the Assessments. Recently performed simulations from the Chemistry-Climate Modelling Initiative (CCMI) will provide core information for the chapters (see article p.37 this newsletter). This will be supplemented by additional work that may appear in the peer-reviewed literature or by other studies that relate to the evolving science questions.

The process for producing the Science Assessments has always undergone change and improvements over the last decades. Given the importance of models for many of the aims of the assessment, the SAP wants to ensure the widespread and consistent use of simulations among the chapters. The SAP Co-chairs decided after the completion of WMO/UNEP (2014) to implement a new structure for delivering numerical model simulations to the Assessment Lead Authors. In particular, the Co-chairs feel that the appointment of two active modellers to the SAP for the 2018 Assessment would facilitate the delivery and analysis of model results. The SAP Co-chairs have therefore invited Drs. Doug Kinnison (NCAR) and Martyn Chipperfield (University of Leeds) to be the SAP Modelling Sub-committee. Their role will be to liaise with the modelling community and advise the SAP Co-chairs regarding model simulations for all chapters in the 2018 assessment. In particular, their duties will include: (1) defining the issues and scientific questions that can be addressed by models (in coordination with the SAP Co-chairs), (2) leading the interface between the Assessment and various existing international organizations (particularly CCMI), (3) defining any additional simulations that would be needed for the 2018 assessment, (4) ensuring that these additional simulations are completed and analyzed in time for the next assessment by directly contacting interested modelling centres (chapter work to begin in early 2017), and (5) coordinating and interfacing with the chapter authors to ensure that the simulations are properly utilized and fulfill the chapter requirements. More information on these activities will be provided via webpages linked to the assessment and CCMI, and in future issues of the SPARC newsletter. In the meantime, any questions or comments on model studies related to the Assessment can be directed to Drs. Kinnison (**dkin@ucar.edu**) and Chipperfield (**M.Chipperfield@leeds.ac.uk**).

Prof. Dr. Karin Labitzke

19.7.1935 - 15.11.2015

Prof. Dr. Karin Labitzke, retired professor of Meteorology at the Freie Universität Berlin, passed away on 15 November 2015 at the age of 80. After completing her PhD at the Freie Universität Berlin in 1962 on "Contributions to the synoptic meteorology of the high stratosphere", she worked with her teacher and mentor, professor Richard Scherhag, who discovered stratospheric warmings. In 1969, she completed her "habilitation" from the Freie Universität Berlin and after the early death of Professor Scherhag in 1970 she took over leadership of the stratospheric research group in Berlin, establishing a successful and internationally renowned research group until her retirement in 2000. Karin contributed significantly to research related to Northern Hemisphere winter sudden stratospheric warmings (SSWs). She showed, for example, that winter polar temperatures vary considerably in the stratosphere: in years with stratospheric warmings monthly mean temperatures in January/February at 30hPa at the Pole could reach -55°C, whereas during cold winters temperatures would be around -75°C. A milestone of stratospheric dynamical research was Karin's finding of a relation between the occurrence of SSWs, the QBO, and the phase of the 11-year solar cycle. Karin published over 250 papers and her book "The Stratosphere" is a popular source of knowledge for PhD students. Besides her research, Karin led the Committee on Space Research, and was member of the Scientific Committee of Solar and Terrestrial Physics and the German Advisory Council on Global Change. Between 1991 and 1993, she was the first female chair of the German Meteorological Society. Through effective third-party fundraising Karin attracted many young scientists whom she supported with a great deal of enthusiasm. Many people knew and appreciated Karin as a colleague, teacher, mentor, and friend. We will always cherish our memories of her.

By Ulrike Langematz and Katja Matthes

The next phase of SNAP: Analysis of the WWRP/WCRP initiative S2S data by the SPARC community

Om Tripathi[1], Andrew Charlton-Perez[1], Greg Roff[2], and Frederic Vitart[3]

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The joint World Weather Research Programme (WWRP)/World Climate Research Programme (WCRP) Sub-seasonal to seasonal prediction project (S2S, **www.s2sprediction.net**) has and is continuing to acquire a large dataset from many operational sub-seasonal forecasting systems. The dataset contains fields in the stratosphere up to 10hPa and provides an excellent opportunity for the stratospheric community to assess the role of the stratosphere in sub-seasonal predictability, since stratospheric variability has been shown to be one of the main sources of predictability that can be exploited for sub-seasonal forecasting (Robertson, 2015). The next phase of the SPARC Stratospheric Network for Assessing Predictability (SNAP) project will involve coordinated analysis of the S2S data by the SPARC community. In this note, we introduce the S2S dataset and propose a way to coordinate analysis of this data. We invite feedback on this proposal from the SPARC community and expressions of interest from those willing to participate in the initiative.

The Sub-seasonal to Seasonal prediction (S2S) project

To bridge the gap between medium-range weather forecasts and seasonal forecasts, the WWRP and WCRP launched a joint research initiative, the Sub-seasonal to Seasonal prediction (S2S) project. This five-year project started in November 2013 and its main goals are to improve forecast skill and understand the relevant processes on sub-seasonal to seasonal timescales. A further objective is to promote the uptake of these types of predictions by operational centres and to promote their exploitation by the applications communities (Vitart *et al.*, 2012). The research topics of the S2S project are organized around a set of six sub-projects (Madden-Julian Oscillation (MJO), Monsoons, Africa, Extremes, Verification, and Teleconnections between mid-latitudes and the tropics), each intersected by cross-cutting research and modelling issues, as well as applications and user needs, as discussed in Vitart *et al.* (2012). A main deliverable of this project is the establishment of an extensive database containing sub-seasonal (up to 60-day) forecasts and reforecasts (sometimes known as hindcasts), complementing the THORPEX Interactive Grand Global Ensemble (TIGGE) database for medium range forecasts (up to 15 days) and the Climate-system Historical Forecast Project (CHFP) for seasonal forecasts. This database will help address important questions for sub-seasonal to seasonal predictability, for instance:

- What is the benefit of a multi-model forecast for sub-seasonal to seasonal prediction and how can it be constructed and implemented?
- What is the sub-seasonal to seasonal predictability of extreme events and how can we identify windows of opportunity for sub-seasonal to seasonal prediction?
- How do models represent sources of sub-seasonal to seasonal predictability (MJO, sudden stratospheric warmings (SSWs), soil moisture) and their impact on extended range forecasts?

Over the past three years, SNAP has reviewed the role of the stratosphere in short-term predictability and completed an experiment looking at the predictability of stratospheric variability in operational NWP models. Following a review of the project by our steering group and discussions with members of the community we have revised the aims of our group to encompass three new driving scientific questions:

- How do monthly forecasting systems predict long-lived stratospheric anomalies and their tropospheric impact?
- Why do some prediction systems fail to capture the amplitude of stratosphere-troposphere coupling?
- Can we develop a test set of experiments and diagnostics to assess the role of different processes in stratosphere-troposphere coupling in models?

Due to the alignment between the aims and objectives of S2S and SNAP, we propose that the next phase of SNAP involves coordinated analysis of the S2S database by the SPARC community. In this document we provide some background on sub-seasonal predictability and stratosphere-troposphere coupling and propose a means by which SNAP can coordinate analysis of the S2S data within the stratospheric dynamics community.

In addition to this coordinated experiment, SNAP will produce and host simple real-time diagnostics of S2S model output on its website. An early prototype can be seen at **www.met.reading.ac.uk/research/stratclim/s2s/forecast**. Forecasts are available three weeks after they are produced and we welcome suggestions from the community on what additional diagnostics could be added to the site.

The Stratosphere as a source of sub-seasonal predictability

The stratosphere, in addition to several other drivers, may provide an additional source of sub-seasonal predictability for surface forecasts through stratosphere-troposphere coupling. Long lasting changes in the strength of the stratospheric polar vortex have been shown to be associated with anomalous tropospheric flow lasting for up to two months in reanalysis data (Baldwin *et al.*, 2003), while Sigmond *et al.* (2013) confirmed that seasonal forecasts initialised during SSW events are more skilful than those which are initialized during non-SSW conditions.

In our recent SNAP study, we confirmed that there are similar gains in skill for operational sub-seasonal forecasts initialised during both SSW events and when the polar vortex is anomalously strong (Tripathi *et al.*, 2015). **Figure 2** shows the anomaly correlation forecast skill for the NAM index at 100hPa and 1000hPa for sub-seasonal forecasts initialised with weak, neutral, and strong initial stratospheric winds. In the troposphere, the skill is significantly enhanced for forecasts initialised during periods of weak and strong stratospheric winds, and the model is capable of capturing persistent anomalies in the NAM throughout the stratosphere and troposphere as well as their impact on tropospheric circulation.

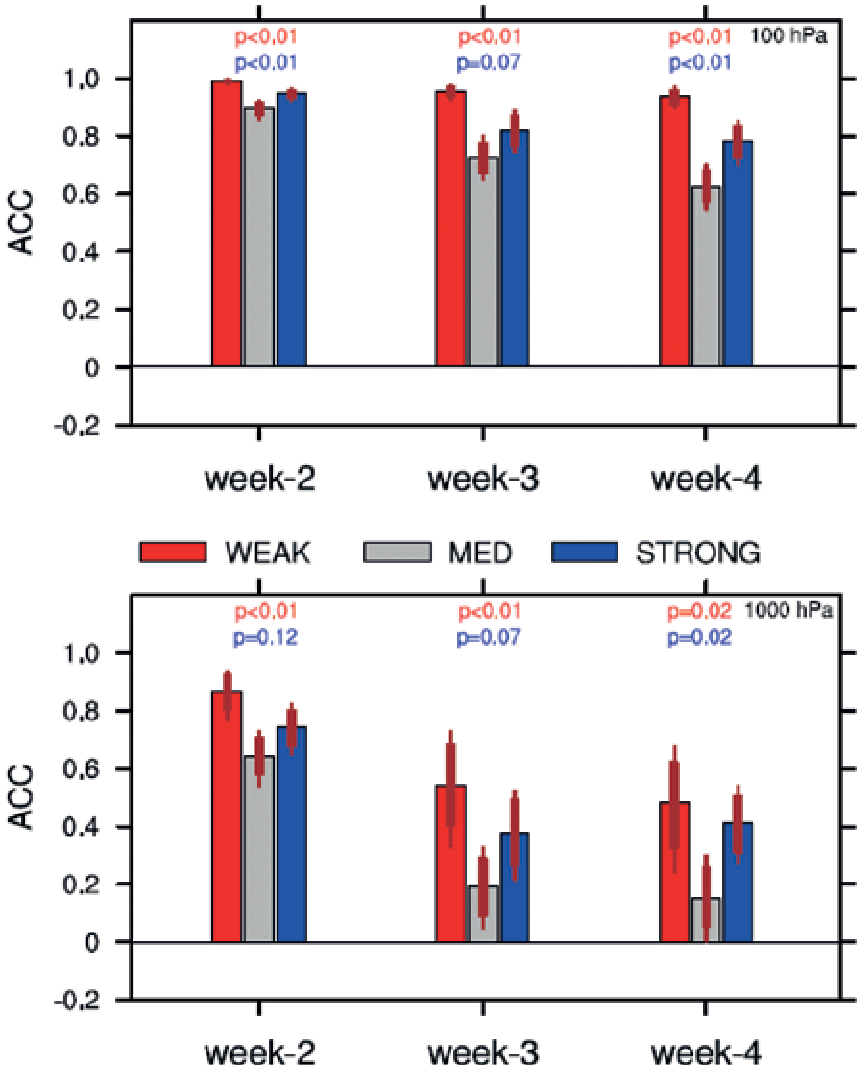

Figure 2: Weekly forecast skill (ACC) for the NAM index at 100hPa and at 1000hPa following weak vortex and strong vortex cases are compared to the skill when the vortex is in a climatological normal state (for more details See Tripathi et al., 2015). NAM is defined as the mean geopotential height anomaly averaged poleward of 60°N. The thick red bars show the forecast skill when the model is initialized for WEAK cases and the blue bars when the model is initialized for STRONG cases. The grey bars show the model skill for the MED cases when the vortex is neither very strong nor very weak. Thin brown error bars show the 95% confidence level calculated using bootstrap sampling. The p-values are calculated for the difference in skill between the MED and WEAK cases (red font) and between the MED and STRONG cases (blue font). P-values indicate the probability that the difference in the skill in WEAK or STRONG cases and MED cases is not because of the anomalous stratospheric state at model initialization. The skill differences between MED and WEAK (STRONG) cases are significant when the thick error bars do not overlap and the p-values are <0.05 (95% confidence level).

Table 1: Details of the models included in the S2S archive. **Ens:** Number of ensemble members produced for the forecast. **Freq:** How often the forecasts are run. **Rfc:** Re-forecasts (hindcasts) are run using the actual forecast model but for past years on the same calendar day as the forecast. The re-forecast is used to calibrate the actual forecast. **Rfc length:** The number of years for which the re-forecasts are run. **Rfc Freq:** Re-forecast frequency. Ideally this should be same as the forecast frequency (freq) but some models run re-forecasts fewer times than the actual forecast. **Rfc Size:** The number of ensemble members for re-forecasts. **fix:** Some operational centres (*e.g.* NCEP) use the same version of their model ("frozen" version) to produce real-time S2S forecasts over a period of several years (typically 4-5 years). Therefore, the same set of re-forecasts can be produced once and used for several years to calibrate the real-time forecasts. **on-the-fly:** Other operational centres (*e.g.* ECWMF) update their model version several times per year. In order to ensure model consistency between real-time forecasts and re-forecasts, the re-forecasts are produced continuously just before the real-time forecast they will be used to calibrate. In some centres, the number of re-forecast years is fixed, but the list of years varies from year to year. See text for abbreviations of modelling centres.

Model	Time-range (days)	Resolution	Ens	Freq	Re-forecast	Rfc length	Rfc Freq	Rfc size
BoM	0-60	T47L17	33	2/week	fix	1981-2013	6/month	33
CMA	0-60	T106L40	4	daily	fix	1994-2014	daily	4
EC	0-35	0.6x0.6 L40	21	weekly	on the fly	past 15y	weekly	4
ECMWF	0-46	T639-319 L91	51	2/week	on the fly	past 20y	2/week	11
HMCR	0-63	1.1x1.4 L28	20	weekly	fix	1985-2010	weekly	10
ISAC	0-32	0.75x0.56 L54	40	weekly	fix	1981-2010	6/month	1
JMA	0-34	T319L60	25	2/week	fix	1981-2010	3/month	5
KMA	0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3
MF	0-61	T255L91	51	monthly	fix	1993-2014	2/monthly	15
NCEP	0-44	T126L64	16	daily	fix	1999-2010	daily	4
UKMO	0-60	N216L85	4	daily	on the fly	1996-2009	4/month	3

The S2S database

The S2S database includes real-time ensemble forecasts and re-forecasts up to 60 days from 11 centres: the Australian Bureau Of Meteorology (BoM), the Chinese Meteorological Administration (CMA), the European Centre for medium-Range Weather Forecasts (ECMWF), Environment Canada (EC), ISAC-CNR, the Hydrometeorological Centre of Russia (HMCR), Japan Meteorological Agency (JMA), Korea Meteorological Administration (KMA), Météo-France (MF), National Center for Environmental prediction (NCEP), and the UK Met Office (UKMO). Most of the models are coupled to an ocean model, and some include an active sea-ice model. Since S2S is a research project, the real-time forecasts are available with a 3-week delay. About 80 fields are archived, including ocean variables, soil moisture, and temperature (**software.ecmwf.int/wiki/display/S2S/Parameters**). Pressure level fields are available in the stratosphere at 50hPa and 10hPa to allow the diagnosis of stratospheric extreme events and their downward propagation (zonal and meridional winds and temperature fields are archived on a total of 10 pressure levels). Daily data is available, except for total precipitation, and maximum and minimum 2m temperature, which are available 6-hourly. Data are currently archived in GRIB2 format, but a netcdf conversion will be made available soon.

The database is archived at two operational centres: ECMWF and CMA. The ECMWF data server (**http://apps.ecmwf.int/datasets/data/s2s**) opened in May 2015 and currently hosts data from seven models (ECMWF, JMA, CMA, NCEP, HMCR, Meteo-France and BoM). Data from all 11 models should be available by the end of 2015. The CMA data portal has also just been opened. Details of the models in the archive are shown in **Tables 1-5**.

Invitation to the SPARC community to use S2S data

We propose that SNAP helps to co-

Table 2: 3D variables available from all models on ten pressure levels (1000, 925, 850, 700, 500, 300, 200, 100, 50, and 10hPa).

Name	Abbreviation	Unit	Frequency
Geopotential height	gh	gpm	Instantaneous once a day (00Z)
Temperature	t	K	Instantaneous once a day (00Z)
U-velocity	u	m.s-1	Instantaneous once a day (00Z)
V-velocity	v	m.s-1	Instantaneous once a day (00Z)

ordinate the analysis of the S2S data in the following ways:

1. SNAP will develop a webpage where researchers from the SPARC community will be able to document their plans for using the S2S data. The purpose of this page is to provide an overview of all planned analyses and to allow collaboration between groups interested in this analysis, following the successful model of the CCMVal and CCMI activities. We propose to send a first e-mail to the SPARC community in early 2016 to ask for further contributions to this webpage by April/May 2016, but the webpage will remain open for contributions after this date.
2. SNAP will organise a discussion of results from the project either as a stand-alone meeting or more likely as a session at another meeting where many of the scientists involved might also attend, one example might be a future AMS Middle Atmosphere Meeting.
3. SNAP will share results from the analysis of S2S data through the project website and links to published papers that result from the analysis. If desired we would also be happy to produce a synthesis and review paper of the results in mid-2017.

The coordinating website (**www.met.reading.ac.uk/research/stratclim/s2s**) will include a table describing planned analysis from the SPARC community. There is a very simple form on the site that researchers can use to contribute their plans and ideas. Table 6 shows current plans from some research groups.

Comments from the community

We invite comments from the SPARC community on this proposal and also expressions of interest to

Table 3: Parameters available on seven pressure levels (1000, 925, 850, 700, 500, 300 and 200hPa).

Name	Abbreviation	Unit	Frequency
Specific humidity	q	kg.kg-1	Instantaneous once a day (00Z)

Table 4: Parameters available on 1 pressure level (500hPa).

Name	Abbreviation	Unit	Frequency
Vertical velocity	w	pa.s-1	Instantaneous once a day (00Z)

Table 5: Parameters available on one potential temperature level (320 K).

Name	Abbreviation	Unit	Frequency
Potential vorticity	pv	K.m2.kg-1.s-1	Instantaneous once a day (00Z)

Table 6: Current plans from research groups.

Project or Group	Lead	Proposed diagnostics or work plan
University of Reading, UK	Andrew Charlton-Perez	A multi-model analysis to study the impact of strong vortex on sub-seasonal predictability. We will make composites of forecasts from models initialised during periods in which the stratospheric vortex is strong and when it is close to climatology. We will use large-scale dynamical fields (Z, T, U) along with surface climate parameters (T2m, precip.)
Seoul National University, Korea	Seok-Woo Son	Influence of QBO on the MJO prediction skill: Using long-term reforecast data sets, the modulation of the MJO prediction skill by the QBO will be examined. The prediction skill and ensemble spread will be quantitatively compared for the westerly and easterly QBO winters.
Seoul National University, Korea	Seok-Woo Son	SSW prediction skill: Extending SNAP phase 1, SSW prediction skill will be examined by analysing reforecast data sets. The models which are initialized at least 4 times a month will be primarily analysed.
Hebrew University, Isreal	Chaim Garfinkel	A multi-model analysis to study the impact of the Madden Julian Oscillation on vortex predictability. The group will make composites of forecasts from models initialised during periods in which the MJO is in its various phases and when tropical convection is disorganized. The group will use large-scale dynamical fields (Z, T, U) along with surface climate parameters (T2m, precip.)

participate in the project and/or join the SNAP steering committee as the project enters its next phase.

References

Baldwin, M.P., D.B. Stephenson, D.W.J. Thompson, T.J. Dunkerton, A.J. Charlton, A. O'Neill, 2003: Stratospheric memory and skill of extended-range weather forecasts. *Science*, **301**, 636-640.

Robertson, A.W., A. Kumar, P. Malaquias, and F. Vitart, 2015: Improving and Promoting Subseasonal to Seasonal Prediction. *Bull. Amer. Met. Soc.*, DOI: 1075/BAMS-D-14-00139.1.

Sigmond M., J.F. Scinocca, V.V. Kharin, and T.G. Shepherd, 2013: Enhanced seasonal forecast skill following stratospheric sudden warmings. *Nature Geosci.*, doi: 10.1038/ngeo1698.

Tripathi, O.P., A.J. Charlton-Perez, M. Sigmond, and F. Vitart, 2015: Enhanced long-range forecast skill in boreal winter following stratospheric strong vortex conditions. *Environ. Res. Lett.*, **10**, 104007.

Vitart F., A. Robertson, and D. Anderson, 2012: Subseasonal to Seasonal Prediction project: bridging the gap between weather and climate. *WMO Bulletin*, **61**, 23-28.

Long-term variations of solar activity and their impacts: From the Maunder Minimum to the 21st century COST ES1005 workshop, 29 September – 2 October 2014, Corfu, Greece

Eugene Rozanov[1,2], Kleareti Tourpali[3], Hauke Schmidt[4], and Bernd Funke[5]

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Solar irradiance over the last decade was marked by an unusually long and deep solar minimum followed by a weaker-than-normal solar maximum. This occurrence has inspired a very active discussion about the possible development of solar forcing in the future and its implications for climate and the ozone layer. The urgency of the discussion stems from the necessity to define a scenario for future solar activity for climate projections within the CMIP6 (Coupled Model Intercomparison Project) activity of the World Climate Research Programme (WCRP). Further complications arise from disagreements concerning the development of total and spectral solar irradiance during the past and the potential influence of energetic particles on the ozone layer and climate. This motivated the participants of the European COST action ES-1005 ("Tosca") and European FP7 project SOLID to organize a workshop in order to discuss ideas how to address these issues.

The workshop on "Long-term variations of solar activity and their impacts: From the Maunder Minimum to the 21st century" was held on the island of Corfu, Greece, from 29 September to 2 October 2014.

The main objectives of the workshop were to:

- Discuss progress in the development of a spectral solar irradiance (SSI) data set based on the available satellite measurements and models;
- Characterize the past and future variations of solar activity;
- Consolidate the current knowledge and understanding of a future change in solar output and its impacts, focusing on the potential transition to lower solar activity (including a grand minimum at the end of the 21st century and its impact on climate);
- Summarize the effects of solar activity on climate with the inclusion of SSI and particle effects on atmosphere and climate, and;
- Discuss the required recommendations for future

climate modelling activities, in particular CMIP6.

In the opening talk, **Hauke Schmidt** reviewed the current knowledge on solar-climate linkages and formulated the desired outcomes of the workshop, emphasizing the need for reliable and accurate SSI products. He also reported on the growing interest of the climate community in accurately simulating solar activity effects in view of a possible decline of solar activity as reflected in a number of recent publications.

Progress in the development of the SOLID SSI data set

Margit Haberreiter introduced the structure of the FP7 SOLID project and described the expected outcomes. She demonstrated recent progress in assimilating SSI observations and reconstructions within the SOLID project and its relevance for long-term projections into both the past and future. She described the key question for any attempt to merge SSI observations: how to combine incomplete and partly overlapping records of noisy observations (and models) into a single composite? SOLID is attempting to tackle this problem by using a Bayesian approach in order to derive a composite that is most compatible with the observations. This method provides the most compatible value (based on objective prior information), performs the data fusion scale-wise (*e.g.* daily, 28-day, 81-day, annual, solar cycle) and requires time-dependent uncertainties. She also presented parallel activities in the framework of an ISSI team on the assessment of the accuracies and uncertainties in the total solar irradiance (TSI) data record and the NASA project MUSSIC (Multi-Satellite Ultraviolet Solar Spectral Irradiance Composite). **Micha Schoell** continued the discussion of the SOLID project, emphasizing that the quality of SSI data can only be characterized if the long-term instrument degradation is properly estimated. He presented different approaches to calculate instrument degradation using either simplified linear component models or comparison of the irradiance for the periods characterized with the same set of physical proxies. An alternative approach could be the direct comparison of two instruments, recursively using each time series as a reference. From the discussion of the information presented it was clear that the SOLID SSI data set will not be completely ready in time for use in CMIP6 experiments and therefore other available SSI data sets will need to be considered. **Stergios Misios** closed the SOLID session by presenting efforts undertaken to better understand the needs of end-users for new TSI/SSI datasets. He presented results from a survey sent to the climate model community and discussed how SSI products have been prescribed in models that participated in several intercomparison activities. He noted that for future projections modelling centres used different approaches in the specification of the solar cycle variation, not always complying with recommendations from SPARC's SOLARIS-HEPPA activity. Regarding the solar forcing recommendations for CMIP6, efforts should be undertaken to ensure a consistent specification of future solar forcing among models.

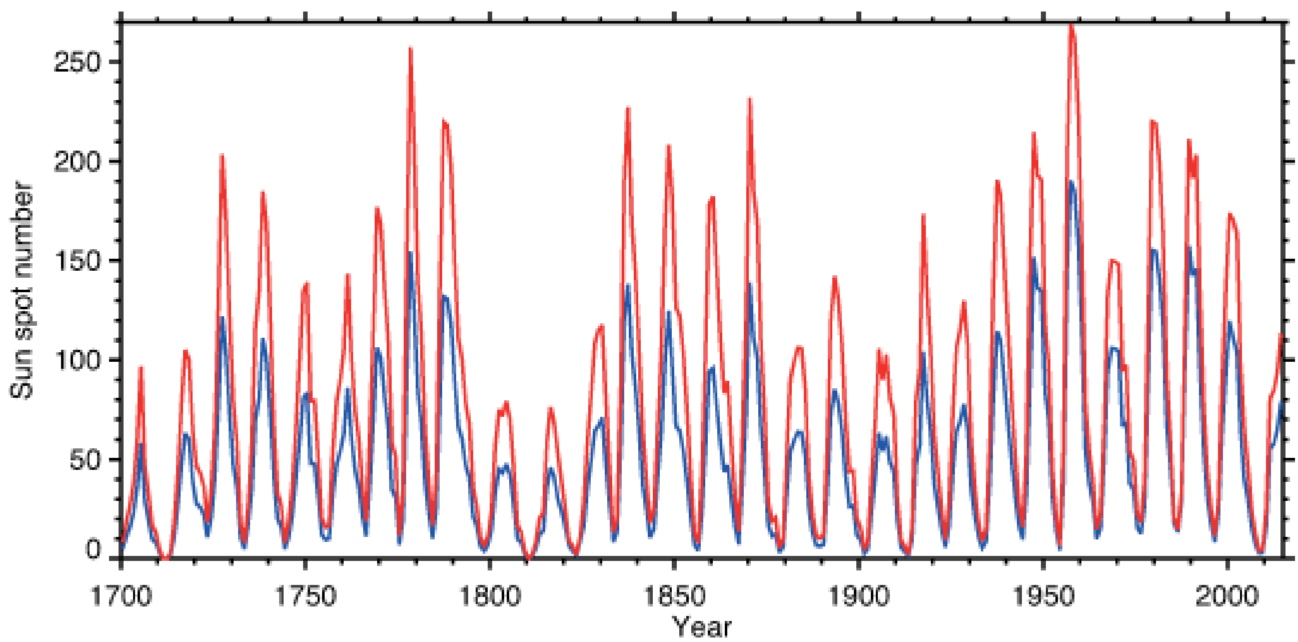

Figure 3: New analysis (red) and uncorrected values (blue) of yearly mean international sunspot number (Sn). Data from the WDC-SILSO, Royal Observatory of Belgium, Brussels (**www.sidc.be/silso/home**).

Past variations in solar forcing

Understanding past solar variability is crucial for the development of future scenarios of solar activity and forcing. It is important to understand how unique the high solar activity period during the last 60 years may have been, and how persistent a potential decline of solar activity in the future might be. The past solar activity can be characterized using different direct observations such as sunspot number or reconstructions from the analysis of radionuclides from ice cores or tree rings. **Laure Lefèvre** presented the multi-faceted pattern of sunspot and sunspot group numbers. Observations of sunspots at the Zurich observatory started in 1749 and different primary observers have continuously carried out measurements ever since. She presented corrections applied to the existing time series of the sunspot and group number in order to account for changes in observers (*e.g.* the "Waldmeier jump") or observation methodology (*e.g.* changes from drawing to photographic plates). When all corrections are applied, the new sunspot time series (see **Figure 3**) reveals a much weaker positive trend from the Maunder minimum to present than previously found. For the latest solar cycle 23, the maximum sunspot number was slightly above 100, while the next solar minimum is expected to take place between 2019 and 2020.

Jürg Beer addressed the long-term variability of solar activity and solar forcing. He discussed difficulties in the reconstruction of solar irradiance variability on centennial and millennial time scales on the basis of solar magnetic field evolution alone. He suggested that if an uncertainty of <0.05% for TSI and SSI is required, then climate modelling and paleo-climate data could be an alternative solution to constrain solar irradiance forcing obtained using solar models and proxies alone. **Natalia Krivova** gave an update on the SSI and TSI reconstructions using the SATIRE-T2 model. More specifically, she concentrated on the possible magnitude of the secular change. The new approach of SATIRE-T2 is to use a simulated distribution of the magnetic field at the surface of the Sun. In the first step, sunspot positions and areas feed into a surface flux transport model to simulate full-disc magnetograms, describing active regions and open flux. These magnetograms are then used in combination with semi-empirical spectra to calculate TSI and SSI. With this approach SATIRE-T2 can provide a consistent SSI/TSI time series going back to the 19th century. She also presented an analysis of past solar activity cycles and concluded that the recent decline of solar activity may not necessarily be the onset of a grand minimum in solar activity. **Alexander Shapiro** also discussed solar irradiance variability on different time scales. He described the COde for the Solar Irradiance Reconstruction (COSIR) and its latest improvements. He briefly presented new calculations of the SSI extending until 2200. He also showed an example of reconstructing Lyman-alpha irradiance time series back to ~1600. He concluded that better constraining the magnitude of the secular trend in solar irradiance requires new observations of fine-scale solar magnetic structures.

Ilaria Ermolli reviewed measurements and the underlying physics of various solar cycle indices that describe variability from the photosphere to the corona. She described the advantages and disadvantages of using sunspot number, group number, and sunspot area. Sunspots are just one of the many different manifestations of the solar magnetic field. An alternative observable of the solar photosphere that spans over more than 100 years is the facular index. Full disk observations of Ca(II)-K or H-alpha of the chromosphere started in the early 20th century and can be used to track the spatial distribution of magnetic flux distribution. She concluded that there is no "best" solar index because different indices represent different solar features. **Timo Asikainen** discussed current issues regarding long-term changes of energetic particle precipitation. He demonstrated that the satellite-observed time series of energetic particle precipitation has been plagued by significant problems related to the MEPED instrument, but reported that some of these problems have been corrected. He also presented efforts to construct a centennial time series of electron fluxes. The final product of this work will be helpful to extend existing solar irradiance time series by adding the reconstruction of energetic precipitating particle forcing, which can also affect the climate system.

Future variations in solar forcing

Scenarios of future solar activity and forcing can be constructed using physically-based or statistical models. At present there are no physical models capable of reproducing the variability of solar magnetic activity on decadal to millennial time scales. Scenarios of the future development of solar activity are therefore mostly based on statistical extrapolation of past solar activity time series. **Katja Georgieva** presented long-term variations and expected future trends of the solar magnetic fields. Information for the solar magnetic field in times without direct observations can be inferred from knowledge of sunspot area. However, she showed that the non-linear dependence of these two quantities differs from cycle to cycle, making future projections uncertain. Nevertheless, analysis of solar physical parameters hints towards weak solar activity at least in the next two solar cycles. She suggested that we are entering a centennial-scale minimum but it is too early to predict if it will be a grand minimum; the SCOSTEP VARSITI project will foster work on this topic. **Mario Stagalini** reviewed recent efforts in understanding the solar cycle variations representing the periodic nature of the solar cycle by trajectories in phase space. He applied a recurrence quantification analysis to various proxies of solar activity and his results indicate that the maximum predictability timescale is of the order of two years for the 10.7cm radio flux and ten years for the sunspot number at solar maxima.

Bernd Funke (with input from **Katja Matthes**) described preparations of the solar forcing data set for the forthcoming IPCC CMIP6 simulations. The historical SSI dataset should cover the period from 1850-2014 and the spectral range from 120-100’000nm with high spectral resolution. He stressed the importance of having well-documented and validated TSI/SSI time series. Apart from the widely used NRLSSI model, a well-documented and validated SSI data set has been produced with the SATIRE model. The presentation also considered the recommendation of forcing by energetic particle precipitation. There are several particle sources (*e.g.* auroral electrons, solar protons, galactic cosmic rays) that affect atmospheric composition and dynamics in the stratosphere. So far, these processes have been included only in a few models. Considering ionization rates from galactic cosmic rays, time series can be extended back in time to cover the required period of 1850-2014. This is not the case for the ionization rates from solar proton events, which are available only since 1962. He discussed the possibility either of omiting proton forcing before 1962 or arbitrarily “reconstructing” forcing by repetition of observed solar cycles. Similar limitations hold for ionization rates of precipitating energetic electrons. For future simulations covering the time period 2014-2300, he presented possible options for solar forcing scenarios, including a reference scenario in which the last three solar cycles will be repeated and an alternative scenario with a super-imposed long term decline to a solar activity state similar to a Gleissberg minimum. In the discussion after the presentation it was pointed out that predictions of future solar activity are generally not feasible. Past solar activity has, however, been characterized by oscillations on secular time scales, which are likely to persist into the future. It is thus rather unlikely that solar activity will remain for the next centuries at the same elevated level as during the last three solar cycles. In the last presentation of this session, **Jan Lastovicka** demonstrated specific features of the upper atmosphere and ionosphere responses to solar forcing under conditions of very low solar and geomagnetic activity. He reported that the solar and geomagnetic activity observed in 2008-2009 is the lowest during the satellite era and even during the era of ionospheric observations. The magnitude of thermospheric neutral density decrease from 2000-2009 substantially exceeds values during previous solar cycles. This decrease appears to be caused predominantly by a substantial decrease of the solar extreme UV flux with a significant role of geomagnetic activity decrease and a minor but non-negligible contribution of CO_2-induced anthropogenic cooling.

Effects of solar activity on climate

This session addressed the importance of different solar forcing agents for the atmosphere and climate. **Pekka Verronen** presented the mesospheric hydroxyl and ozone responses to energetic electron precipitation events from 2002-2012. He provided evidence for measurable changes at the surface owing to particle precipitation, but cautioned that a complete understanding of ozone variability caused by particle precipitation is still missing. The direct HO_x effect of radiation belt electrons on mesospheric ozone has been observed and needs to be included in future modelling studies. **Ingrid Cnossen** presented the atmospheric response to long-term changes in Earth’s magnetic field, demonstrating that variations of the magnetic field play an important role for long-term changes in the ionosphere but also in the thermosphere. Some of the proposed mechanisms for ionosphere-thermosphere coupling have been included in the WACCM-X model, which simulates significant changes in neutral temperature and winds in the upper atmosphere in response to geomagnetic disturbances. She also showed that upper atmospheric changes appear to influence lower regions of the atmosphere, with the response depending on both longitude and season. **Jürg Luterbacher** discussed the possibility of a detectable solar influence on European summer temperatures since the Maunder Minimum. He presented results from a new reconstruction of central European summertime temperatures using tree rings with an annual time resolution. This time series exhibits periodicities that could be attributed to solar cycle forcing, with stronger signals found in Western Europe (although this may not be directly attributed to a stronger solar influence in this region). He concluded by suggesting that climate models could be used to constrain paleoclimate reconstructions. **Stergios Misios** presented results from the SolarMIP activity. The models that participated in CMIP5 show realistic temperature changes in the stratosphere albeit of weaker amplitude compared to reanalysis products. The surface response is characterized by a warming delayed by about two years with respect to the solar cycle maximum. He also discussed possible mechanisms explaining regional patterns of the response of surface temperature to solar irradiance variability.

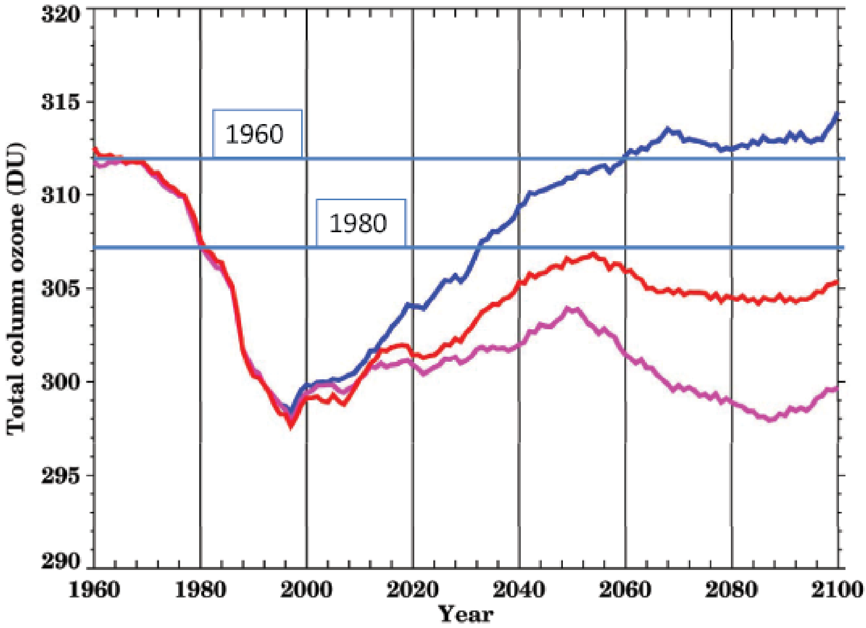

Figure 4: Global annual mean total column ozone (in Dobson units) from 1960 to 2100 as simulated by the SOCOL AOCCM MPIOM. The blue line represents a case with constant solar activity. Red/Pink lines represent the case with a strong decline of the solar activity for weak/strong strength scenarios of SSI evolution (see Anet *et al.*, 2013 for the experiment description). Results are smoothed with 7-year running average.

Impacts of future solar variability

The final session was devoted to a discussion of the implications of a potential decline of solar activity on the atmosphere and climate. **Eugene Rozanov** described responses to a potential decrease of solar activity in the 21st century using simulations from the coupled SOCOL-MPIOM model. Using the RCP4.5 scenario and several different scenarios for solar activity he showed that the decrease in solar irradiance resulted in a compensation of 0.3 K (~20%) globally and locally up to 1.0 K (~35%) of greenhouse warming at the surface. Furthermore, the prescribed solar irradiance decrease led to a more than 100% amplification of the cooling in the upper atmosphere from greenhouse gases. The model also showed that in the case of strongly declining solar activity global ozone recovery could be completely cancelled (see **Figure 4**). This calls for stronger limitations on the emission of ozone depleting substances. He also mentioned that the efficiency of the so-called top-down mechanism (allowing for a downward propagation of solar signals from the stratosphere to the surface) in the model was not large enough to compensate for greenhouse warming over the Northern Hemisphere landmasses during winter.

Amanda Maycock also reported results from a similar experiment looking at future climate projections with a decline in solar activity using the Hadley Centre climate model. These simulations suggest a shift of the North Atlantic Oscillation to more negative values in combination with amplified signals over Siberia and eastern Europe. The simulated responses are likely related to the "top-down" mechanism, but she stressed that whilst different bottom-up/ top-down mechanisms have been demonstrated in isolation, we do not have a good understanding of the relative importance of each of them in the real world or in models.

Conclusions

The workshop provided a great opportunity for climate modelling and solar physics communities to discuss the current understanding of solar activity and its impacts on climate. The results presented confirmed that the variability of solar forcing is important for the ozone layer and climate. A lot of time was dedicated to the discussion of requirements for upcoming CMIP6 project. With regard to SSI and TSI products, it was recommended that the best-documented and most validated data set be considered. The inclusion of particle effects as a recommended forcing also attracted much attention because their potential importance for the ozone layer and climate was established using analyses of observational data and model simulations. For future reference simulations, one possibility could be to repeat several cycles from the turn of the 19th century. However, an alternative scenario with a long-term decline of solar activity could also be envisaged. The probability of a new deep minimum in solar activity cannot be accurately established using available data, but it seems not to contradict our understanding of solar activity behaviour on long timescales. Participants agreed that a solar activity decline would only weakly compensate global warming by greenhouse gases, but could have substantial implications for the recovery of the ozone layer. On the regional/seasonal scale the compensation of the greenhouse warming by solar activity decline could be larger, but this conclusion has not been confirmed with a sufficient number of models. Recent developments showed that the workshop had an important impact on the SOLARIS-HEPPA solar forcing recommendations for the CMIP6 activity regarding the consideration of SATIRE as an alternative/additional SSI data source to NRLSSI (used in previous studies such as CMIP5), and regarding the construction of a more realistic future scenario taking into account secular variations. All participants also agreed on the absolute necessity of continuous monitoring of TSI, SSI, energetic particle precipitation, and solar-related essential climate variables.

Over the past year, the issues raised at this workshop have been further discussed at several international conferences, meetings, and workshops. The most important updates concern solar forcing scenarios for CMIP, which will be provided as both SSI and TSI data sets for historical and future periods. These data sets will be based on merged NRLSSI2 and SATIRE products instead of using one particular model. The proposed future solar activity scenario will be based on a combination of several statistical forecast methods and will include a declining solar activity phase (similar to the Gleissberg minimum level) and a recovery to long-term mean activity around 2100. Consistent scenarios for the forcing from some of the precipitating energetic particles will be also provided. A more in-depth article on recent progress in solar-climate research will be included in an upcoming edition of the SPARC newsletter.

Reference

Anet, J. *et al.*, 2013: Impact of a potential 21st century "grand solar minimum" on surface temperatures and stratospheric ozone, Geophys. *Res. Lett.*, **40**, 4420–4425, doi: 10.1002/grl.50806.

Report on the 2nd Workshop on Atmospheric Composition and the Asian Monsoon (ACAM)

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As a weather pattern, the Asian monsoon impacts the lives of more than a billion people. Dynamically, the anticyclonic flow during the Asian summer monsoon (ASM) in the upper troposphere and lower stratosphere (UTLS) dominates the seasonal flow pattern in the Northern Hemisphere. The region has also experienced rapid population and economic growth in recent decades. Satellite observations have provided clear evidence that ASM convection coupled to surface emissions has a global impact on atmospheric composition (Randel *et al.*, 2010). The ASM is increasingly recognized as a phenomenon bridging regional air quality, climate change, and global chemistry-climate interactions. Collaborative efforts across the monsoon-region countries and with the international community are needed to characterize and quantify the regional and global impacts of this system. The Atmospheric Composition and the Asian Monsoon (ACAM) initiative, jointly sponsored by SPARC and IGAC, is intended to build this community and help guide the effort necessary for making scientific progress.

Figure 5: Participants of the 2nd ACAM workshop held in Bangkok, Thailand.

Building on developments from the initial workshop held two years earlier in Kathmandu, Nepal, the 2nd ACAM workshop was held from 8-10 June 2015 in Bangkok, Thailand. One hundred and seventy scientists representing 22 countries attended the event (**Figure 5**). The workshop was organized jointly by the ACAM scientific steering committee and the 2nd workshop local organizing committee (**www2.acom.ucar.edu/acam/bangkok-2015-committee**).

The three-day meeting opened with an introductory session consisting of project overviews, sponsor expectations, and ACAM science overviews. Two invited scientific overview presentations provided a strong start to the meeting with **Guy Brasseur** emphasizing the importance of Asian emissions and monsoon meteorology to global chemistry and climate. He was followed by **Bill Lau** who provided an assessment of current understanding of aerosol impacts and feedbacks on the Asian monsoon, highlighting areas of uncertainty needing attention. Following the overview session, the scientific research presentations included both oral and poster sessions. Sessions were organized into three topical areas: Emissions and Air Quality, Aerosols and Clouds, and Convection and UTLS. Community building activities were further developed in the working group breakout discussions. The workshop concluded with brief reports on the status of on-going and future field activities and open floor discussions. The meeting agenda and links to material presented at the meeting are available at: **www2.acom.ucar.edu/acam/bangkok2015**.

Scientific Highlights from the Workshop

Broad representation of Monsoon Asia regional measurements

Emission trends from space observations have increasingly been referenced as an indication of rapid change and deteriorating air quality

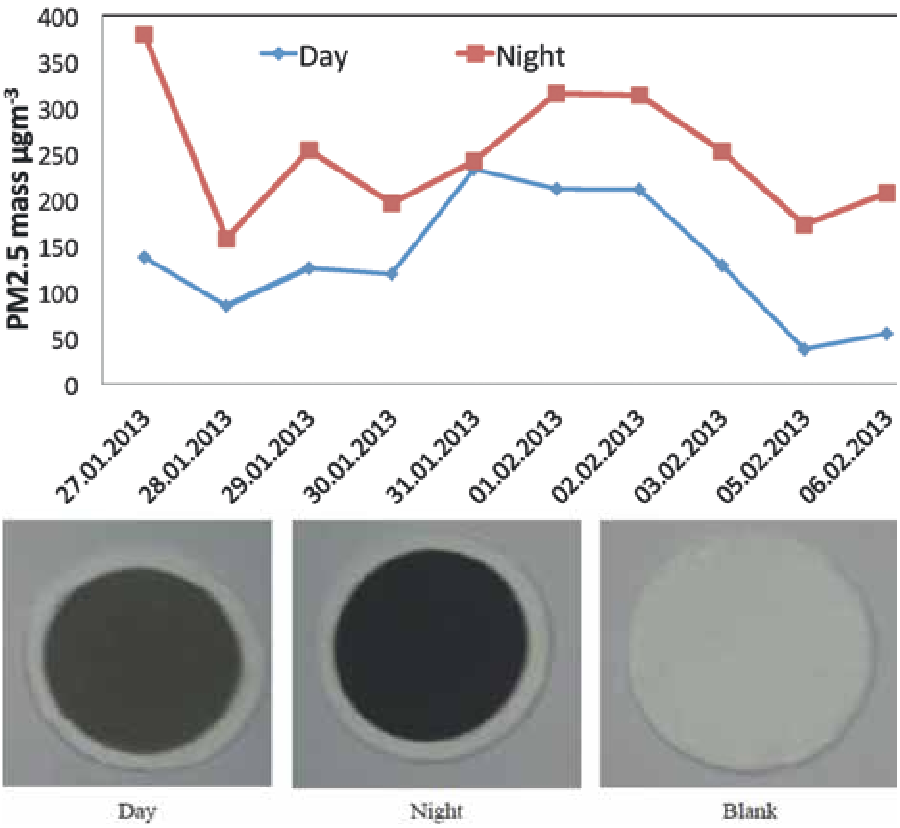


Figure 6: PM2.5 measurements in Dhaka, Bangladesh. Aerosol particulate matter (PM2.5) was collected with an Envirotech instrument (Model AFM 550) on Quartz filters (Gelman, Membrane Filters, Type TISSU Quartz 2500QAT-UP, 47mm diameter) on the roof (34m altitude) of Mukarram Hussain Khundkur Science Building, Department of Chemistry, University of Dhaka, during winter 2013. The average sampling time was about 12 hours (7:00pm to 7:00am) considered "night-time" and about 9 hours (7:30 am to 6:30 pm) considered "day-time". (Unpublished data, for reference see Salam *et al*., 2003).

over Asia. Regional observations are essential for characterizing the complexity of this problem and for source attribution. These ground-based measurements across the monsoon Asia region were well represented at the workshop. Presentations included descriptions of local measurements and activities to monitor air pollution from India, Vietnam, Myanmar, Bangladesh, Indonesia, Pakistan, Taiwan, Thailand, Nepal, China, and Singapore.

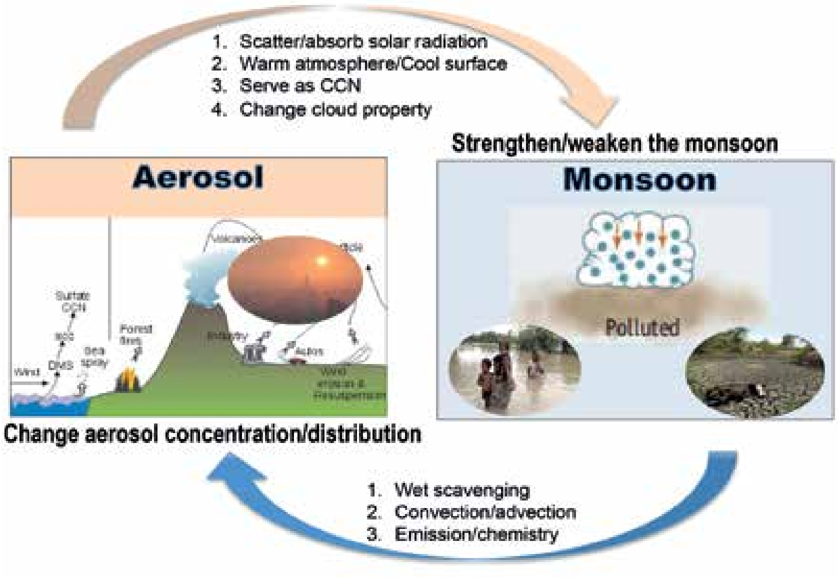


Figure 7: Schematic of aerosol-monsoon interactions.

Figure 6 shows an example of PM2.5 measurements from Dhaka, Bangladesh, from the presentation by **Abdus Salam** of Dhaka University. A strong diurnal behaviour was identified, with the average night-time PM 2.5 mass (249.1µg/m^3) almost double the day-time value (134.5µg/m). This strong contrast was attributed to a combination of the high emissions from heavy-duty traffic vehicles (trucks and lorries) that are allowed to drive in the city only during the night and the night-time temperature inversion.

Interaction between pollution and the Monsoon

Aerosol-cloud/Monsoon interaction is one of the four ACAM science themes. The 2nd workshop engaged a significant interest on this topic from the AeroCom community (**http://aerocom.met.no**), which works on investigations of aerosol-Monsoon interaction using an integrated approach of model simulations and comparisons with observations. A schematic of the specific set of science questions is shown in **Figure 7**, presented by **Mian Chin**. She presented initial results from a modelling study to investigate the question of whether a weaker Monsoon could result in dirtier air. Using the NASA global model with the GOCART aerosol component in combination with aerosol observations over south and east Asia from 1980 to 2009, results showed that there is a positive difference in surface PM2.5 for the summer season (JJA) between the four weakest and four strongest Monsoon years. Results also showed that Monsoon-related variability is still much smaller than the contribution of increased anthropogenic emissions to the worsening regional air quality. The related question of how these changing emissions impact the strength and behaviour of the Monsoon circulation is an important open research topic for the community.

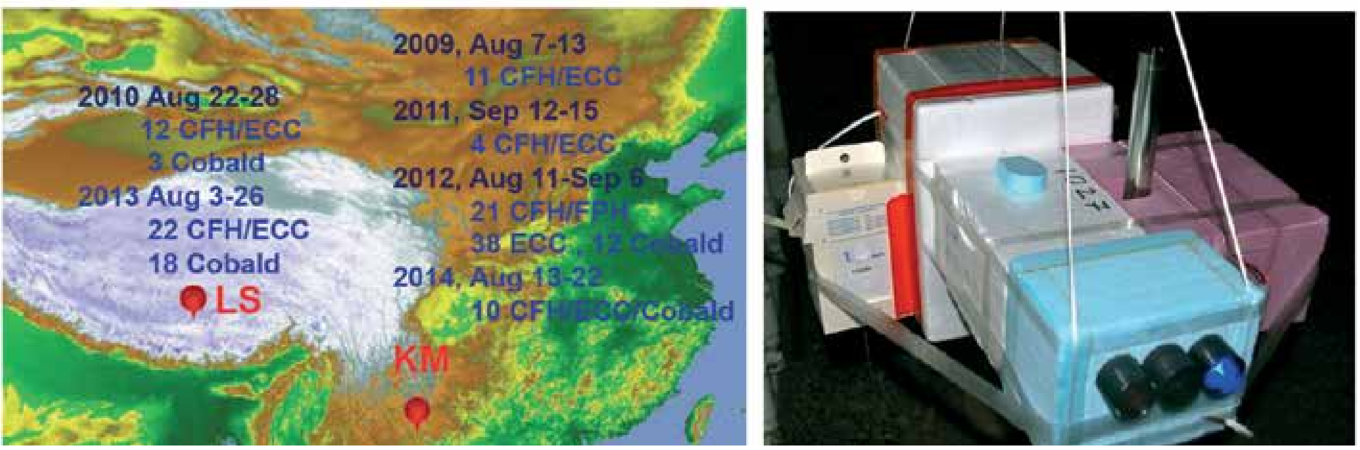
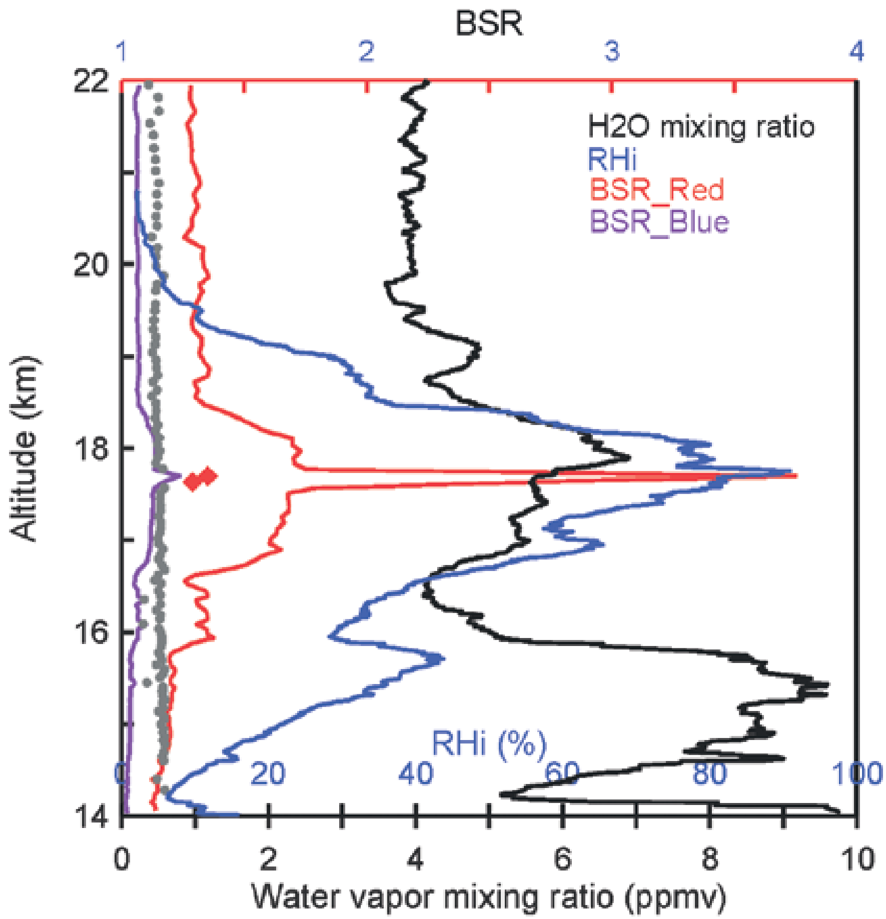


Figure 8: Left: Locations and number of sondes launched for the first six years of the SWOP project (LS: Lhasa, KM: Kunming). Right: Image of the integrated four-sensor payload with ECC, RS, CFH/FPH, and COBALD.

Figure 9: Example of a sounding from the SWOP campaign for 13:00 UTC on 19 August 2014 (unpublished data presented by Jianchun Bian). The UTLS profiles of water vapour mixing ratio (black line) and relative humidity (RHi) (blue line) indicate multiple layers between 14-20km altitude. In particular, the layer between 16-19 km contains a broad aerosol layer and a narrow cirrus cloud layer at 17.7km where the RHi is near 100%, both indicated by the backscatter ratio (BSR) of 940nm (red line) from COBALD. The identification is from the colour index (CI) of 940nm over 455nm (grey dots and red diamonds represent aerosol and cirrus, respectively, and share the same scaling as RHi). CI values near 5 indicate aerosol particles and values above 10 are associated with cirrus particles.



Growing activities focused on the monsoon impacts on UTLS composition

In situ measurements of the UTLS during the ASM anticyclone period are key to characterizing and quantifying the climate impact of Monsoon convection. **Figure 8** shows the locations and number of launches conducted over the Tibetan plateau during the Sounding of Water vapour, Ozone and Particle (SWOP) project. SWOP is an on-going project with six years of data (2009-2014), led by **Jianchun Bian**. The balloon-sounding payload is optimized to have four sensors: radiosonde, ozonesonde, Frost Point Hygrometer (FPH) or Cryogenic Frost Point Hygrometer (CFH), and Compact Optical Backscatter Aerosol Detector (COBALD). The payload produces simultaneous profiles of pressure, temperature, relative humidity, water vapour, ozone, aerosol particles, and cirrus clouds. **Figure 9** shows an example of such measurements, revealing the layered structure of relative humidity, cirrus clouds, and aerosol in the UTLS. These are among the very first measurements that verify the existence of the Asian Tropopause Aerosol Layer (ATAL), originally identified using CALIPSO space lidar data (Vernier *et al.*, 2011).

Additional *in situ* aerosol measurement capabilities were presented by **Gwenaël Berthet** and **Ru-shan Gao**. Gwenaël's presentation focused on the design and application of a light optical aerosol counter (LOAC) that can be launched with weather balloons. LOAC was used during the Balloon Measurements of the Asian Tropopause Aerosol Layer (BATAL) campaign, led by Jean-Paul Vernier. Past campaign results using the LOAC were also discussed. **Figure 10** shows the LOAC, the campaign location, and an example of expected results. Note that BATAL 2015 took place from Varanasi, India, in August 2015, two months after the workshop.

Ru-Shan Gao's poster presentation showed a new light-weight instrument developed by NOAA's Chemical Science Division, the Printed Optical Particle Spectrometer (POPS). With a weight of just 800g, it is designed to be integrated on to balloon sounding payloads. POPS was also launched two months after the workshop during the 2015 SWOP campaign.

Model simulations of ASM transport have been conducted in preparation for the StratoClim Asian monsoon field study, planned for 2016 using the Geophysica research aircraft (**http://www.stratoclim.org**). **Figure 11** shows an example presented by **Rolf Müller** based on the work of Vogel *et al.* (2015). The figure indicates that Monsoon convection effectively

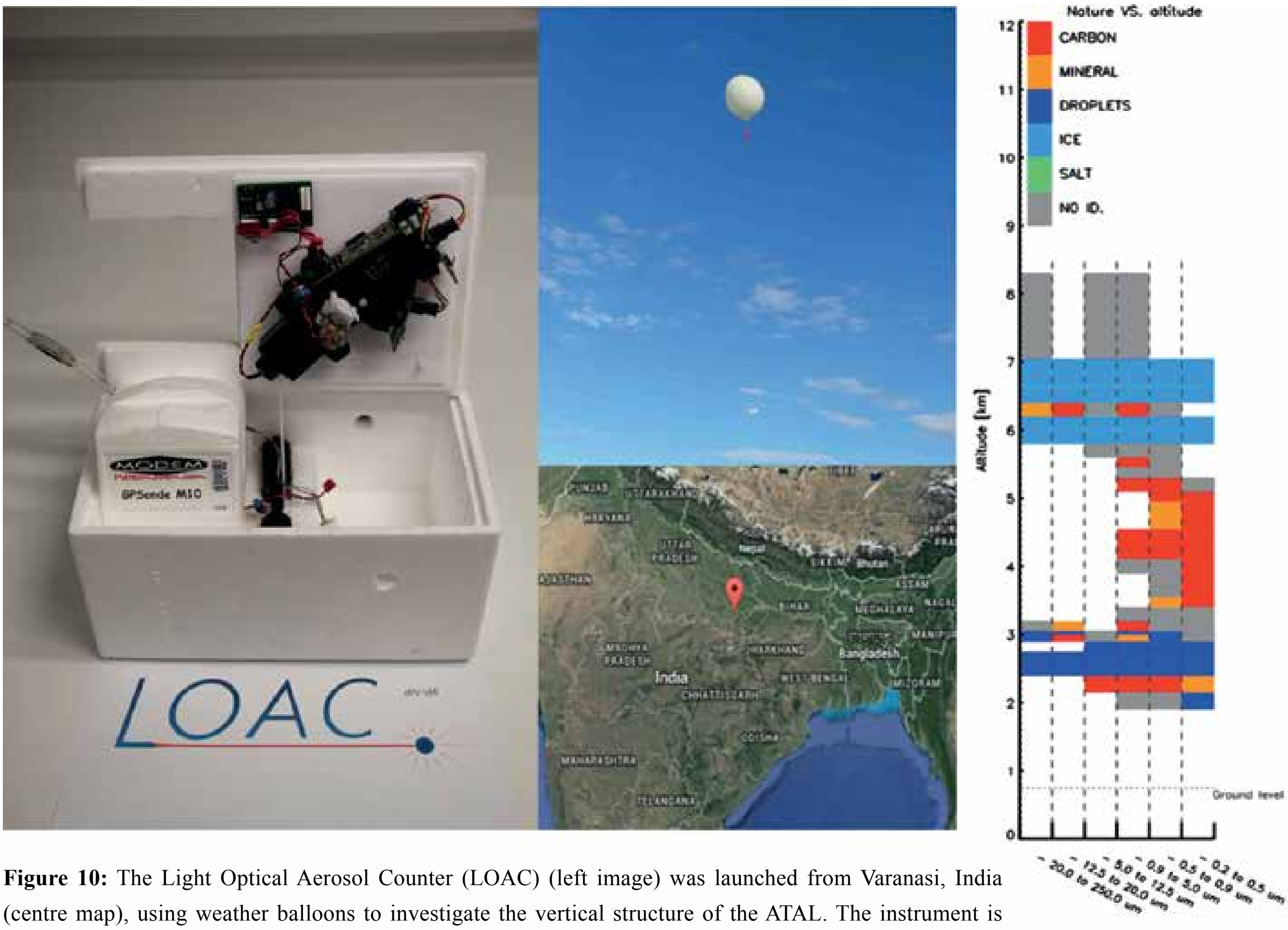


Figure 10: The Light Optical Aerosol Counter (LOAC) (left image) was launched from Varanasi, India (centre map), using weather balloons to investigate the vertical structure of the ATAL. The instrument is designed to provide information about particle size and type, *i.e.* water droplets, aerosols with a carbonaceous content, minerals, sea salt, and possibly ice, as indicated by the figure on the right, which is from a past campaign and was shown as an example of expected results.

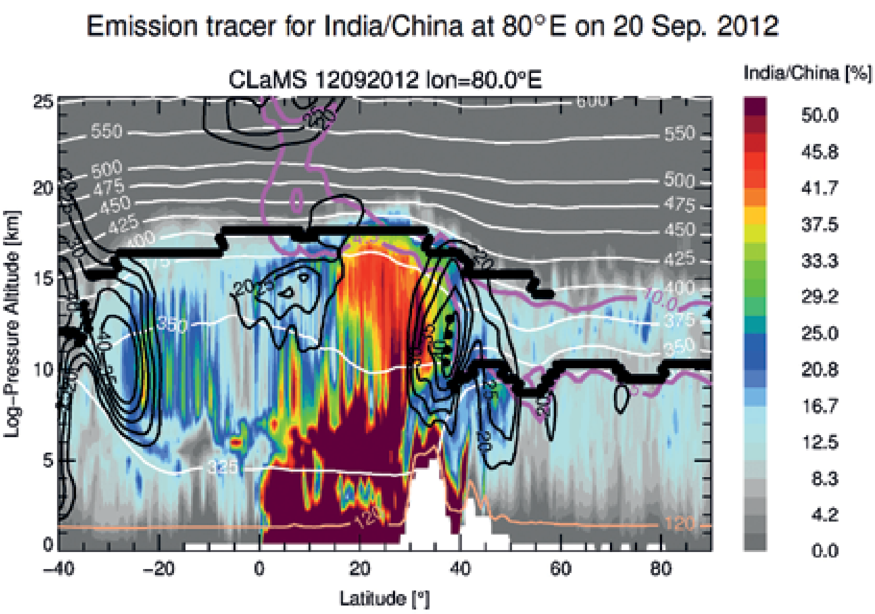


Figure 11: Fraction of air originating from India/China simulated with the CLaMS model in a latitude-height cross-section on 20 September 2012 in the Asian Monsoon region (15-35°N latitude, 80°E longitude). The coloured shading shows the emission tracer distribution. The dynamical background is indicated using wind velocity (black lines), potential temperature (thin white lines), thermal tropopause (black dots), and the 4.5 and 10PVU surfaces (purple).

pumps the local emissions up to the tropopause level. To what extent the tropopause serves as a transport barrier is an open question that is to be investigated by the aircraft campaign.

Community and Capacity Building

Enthusiastic participation in working group discussions

Working Group discussions were a critical element of the workshop that allowed scientists to discuss how to promote ACAM science and collaboration. Attendees engaged in the working group discussions and contributed ideas on steps forward for each activity. The group for Data Sharing reported growing membership and an increasing number of datasets relevant to ACAM science including surface, airborne, and satellite datasets. Development of a web site to assist in data discovery is a major goal. The group for promoting partnership with CCMI (Chemistry-Climate Model Initiative) emphasized that efforts to improve climate models require input from a broad perspective that includes more than just modellers. They also suggested that the group expand to connect ACAM with other community modelling projects (*e.g.*, AeroCom, MICSAsia, HTAP, SSiRC). The group for Field Campaigns shared an impressive list of activities including surface measurements, sounding programs, and planned airborne campaigns that will provide much needed information that will benefit from coordination. Finally, the group for Training emphasized the training school taking place in association with the workshop and discussed other suggestions on how to best serve the ACAM community.

Successful 1st ACAM training school following the workshop

Following the three-day workshop, the first ACAM training school was held on 'Satellite and Model Data use for Aerosols and Air Quality', hosted at the Asian Institute of Technology, Bangkok. The training school was organized by the ACAM working group co-leads **Ritesh Gautam**, **Federico Fierli**, and **Mary Barth**. There were 33 participants, selected from more than 100 applicants and representing 12 Asian countries. The training school brought together international experts in satellite remote sensing and modelling to provide focused tutorials on aerosols, air quality, trace gases, emissions, and transport.

A highlight of the school was the 'Science Café' discussion after dinner on the first day. Small groups (6-8 students and lecturers) put together ideas of ACAM-related science projects with a theme of 'Climate and Air Quality in Asia: Processes, Impacts, Mitigation'. Each group presented their research objective and how they would achieve that objective through measurements and modelling. The discussion was beneficial in allowing the participants to get to know each other better and fostering relationships for potential future interdisciplinary collaborations.

The ACAM workshop enabled participation in related activities of common interest. These included the first ACAM Training School, the IGAC-MANGO Workshop, and a side meeting on Winter Fog sponsored by ICIMOD.

Applications to attend the ACAM workshop far outpaced the capacity that could be accommodated. Many worthy applicants had to be turned away, but achieving the goals of ACAM depends on participation beyond the workshop. Joining the ACAM mailing list and becoming an active member of one of the working groups is encouraged. Interested researchers are invited to send an email to **acam-request@acd.ucar.edu** to join the mailing list, and to contact relevant working group leaders found at **www2.acom.ucar.edu/acam/working-groups**.

Acknowledgements

Participating countries: Bangladesh, China, France, Germany, India, Indonesia, Italy, Japan, Korea, Malaysia, Myanmar, Nepal, Pakistan, Philippines, Saudi Arabia, Singapore, Switzerland, Taiwan, Thailand, United Kingdom, United States, Vietnam
Host Institutions: King Mongkut's Institute of Technology, Ladkrabang, and the Asian Institute of Technology
Sponsoring Organizations: IGAC, SPARC, IAMAS, National Natural Science Foundation of China, National Institute for Environmental Studies (Japan), ICIMOD, IASS, NASA, NSF, IGBP, iCACGP, WCRP.

References

Randel, W.J., M. Park, L. Emmons, D. Kinnison, P. Bernath, K.A. Walker, C. Boone, H. Pumphrey, 2010: Asian Monsoon Transport of Pollution to the Stratosphere. *Science*, **328**, 611 – 613, doi: 10.1126/science.1182274.

Salam *et al.*, 2003: Aerosol chemical characteristics of a mega-city in Southeast Asia (Dhaka-Bangladesh). *Atmos. Env.*, **37**, 2517-2528.

Vernier, J. -P., T.D. Fairlie, M. Natarajan, F.G. Wienhold, J. Bian, B.G. Martinsson, S. Crumeyrolle, L.W. Thomason, K.M. and Bedka, 2015: Increase in upper tropospheric and lower stratospheric aerosol levels and its potential connection with Asian pollution. *J. Geophys. Res. Atmos.*, **120**, 1608–1619. doi: 10.1002/2014JD022372.

Vogel, B., G. Günther, R. Müller, J.U. Grooß, M. and Riese, 2015: Impact of different Asian source regions on the composition of the Asian monsoon anticyclone and on the extratropical lowermost stratosphere. *Atmos. Chem. Phys. Discuss.*, **15**, 9941-9995, doi:10.5194/acpd-15-9941-2015.

The Width of the Tropics: Climate Variations and Their Impacts

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An American Geophysical Union (AGU) Chapman Conference on "The Width of the Tropics: Climate Variations and Their Impacts" was held in Santa Fe, New Mexico, USA, from 27-31 July 2015. The conference was convened by Sean Davis, Thomas Birner, Dian Seidel, and Lorenzo Polvani to address the theoretical, observational, and societal aspects of the changing width of the tropical belt.

The week began with a Monday evening public lecture by **Bob Davis** on "Global Warming and Human Health." He highlighted the complex interactions between human health and the direct (heat-related) effects of global warming, the indirect effects of global warming (*e.g.* changes to air pollution, water quality, tropical width), and social dynamics. He responded to questions from members of the audience, who appreciated the opportunity to attend the lecture as part of their stay in Santa Fe.

Over 50 scientists from North America, Asia, Europe, and Australia participated, presenting papers and posters in four sessions that addressed different aspects of the tropical width issue:

1. What determines the width of the tropical belt?
2. How and why has the width of the tropics changed in the past?
3. How and why might the width of the tropics change in the future?
4. What are the impacts for the oceans, cryosphere, hydrological cycle, human society, and ecosystems?

What determines the width of the tropical belt?

The opening session, entitled "What determines the width of the tropical belt?" was brief, but diverse. Discussions about three dichotomies of the width of the tropics characterized this session: (1) whether the width of the tropical belt is determined by tropical thermal heating or by atmospheric eddies, (2) whether the width of the tropical belt is best understood in a zonal-mean (*i.e.*, tropics-wide) or regional-scale perspective, and (3) whether the width of the tropics is best described by a single metric, or whether multiple metrics are appropriate.

When the tropical overturning circulation is considered as a whole, the dynamical principles governing its width can be largely reduced to contrasting contributions from the following two effects: (1) changes in thermal structure (such as warming in the deep tropics) and (2) eddy heat and momentum fluxes (such as those associated with a shifting jet stream resulting from warming global sea surface temperatures). Keynote speaker **Isaac Held** began the session by highlighting the first dichotomy, noting that eddy fluxes aloft play a direct role in determining the width of the Hadley cell, but that thermal forcings coupled to angular momentum conservation may also influence the width of the Hadley cell.

The discussion of eddies continued later in the session, with **Paul Staten** citing changing eddy fluxes, specifically due to changing wave reflection, as a causal factor in Hadley cell widening in models. **Nick Davis** attributed climate model biases in the tropical width with increasing horizontal resolution to an intensification of wave activity. **Ori Adam** showed that the modeled Hadley cell width is more sensitive to the meridional temperature gradient than to the mean temperature, which also suggests a strong role of eddies.

With a contrasting emphasis on thermal forcing, a poster by **Dian Seidel** and co-authors used geoengineering model simulations performed as part of the GeoMIP project to highlight the role of simple changes in radiative forcing and the importance of the deep tropical temperature structure in the response of the Hadley circulation width. Simulated CO_2-induced warming is associated with widening of the Hadley cell, which is largely offset by reducing the solar constant.

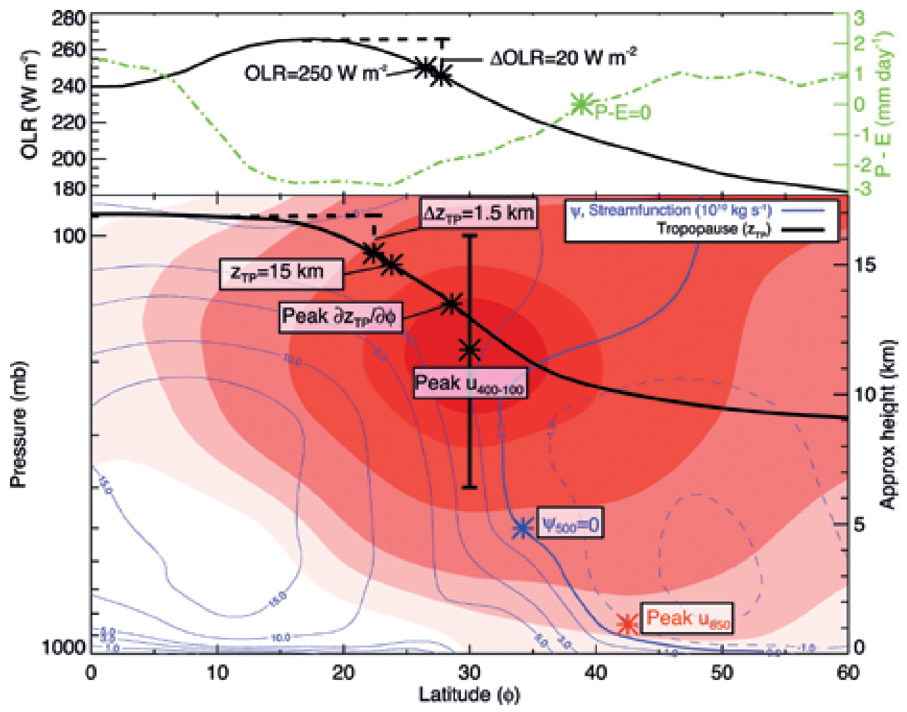

Figure 12: Schematic illustrating zonal mean metrics for the width of the tropics. The top panel shows outgoing longwave radiation (OLR) and precipitation-minus-evaporation (P-E) thresholds, while the bottom panel highlights tropopause (TP) height thresholds as well as dynamical thresholds involving westerlies (U) and the meridional streamfunction (Ψ). Note that the peak near-surface westerlies (U_{850}) are generally used as a measure of the eddy-driven jet, rather than the Hadley cell edge. From Davis & Rosenlof (2012).

The dynamical framework outlined by Isaac Held focuses on the tropics as a whole, but the tropical circulation has its greatest impacts on a regional level. This second dichotomy was explored by **Christopher Karnauskas**, who highlighted the role of east-to-west temperature gradients along eastern ocean basin margins – which by construction average to zero in tropics-wide analyses – to the strength and extent of the Hadley cell in localized regions of the tropics. Posters by **Talal Alharbi** and **Thomas Birner** likewise highlighted additional specific, regional examples of tropical circulation change.

While it is clear that regional tropical circulation patterns can vary strongly from their global counterparts, it is less clear how these regional and global changes are to be defined. This third dichotomy is the contrast between, 'What sets the width of the tropics?'and 'What defines the width of the tropics?'

Dian Seidel noted the variety of metrics for Hadley cell and tropical width. Often these metrics vary depending on the impact in question. Eager to study the relationship between tropical width and stratospheric ozone, **Susann Tegtmeier** and colleagues studied the changing Lagrangian cold point (LCP). They found that the LCP has been shifting poleward by about 1.2° per decade for the period 1979-2011, which is on par with metrics for the entire Hadley cell circulation boundary. **Melody Avery** related tropical width to cloudiness by examining thin cirrus measurements from nine years of homogenized LIDAR data from CALIOP onboard the CALIPSO satellite. **Chi Ao**, **Seok-Woo Son**, **Sean Davis**, **Carl Mears**, and **Hong Yan** measured tropical width variability based on radio occultation, pressure ridging, column ozone gradients, vapour pressure, and climate proxy data, respectively. Each metric highlighted some unique aspect of seasonal, regional, or interannual variability associated with the tropical circulation. The sheer quantity of metrics began a discussion about their utility that continued throughout the conference.

How and why has the tropical width changed in the past?

The second session of the meeting focused on quantifying how much the width of the tropics has changed in the past as well as identifying the underlying causes of these changes. Keynote speaker **Karen Rosenlof** pointed out that this topic is greatly complicated by the large number of metrics for tropical width used in previous studies, which makes the comparison of results across studies challenging. Some metrics for tropical width focus on dynamical or hydrological thresholds near the surface (**Figure 12**). Other metrics for tropical width focus on changes at higher altitudes, such as shifts in cloud fields (**Ryan Eastman**), shifts in the upper tropospheric jet streams (**Gloria Manney**), and changes to the tropical upwelling patterns in the lower stratosphere (**Karen Rosenlof**). It was agreed that a better physical sense of what each of these metrics represents and how they are related to one another should be established.

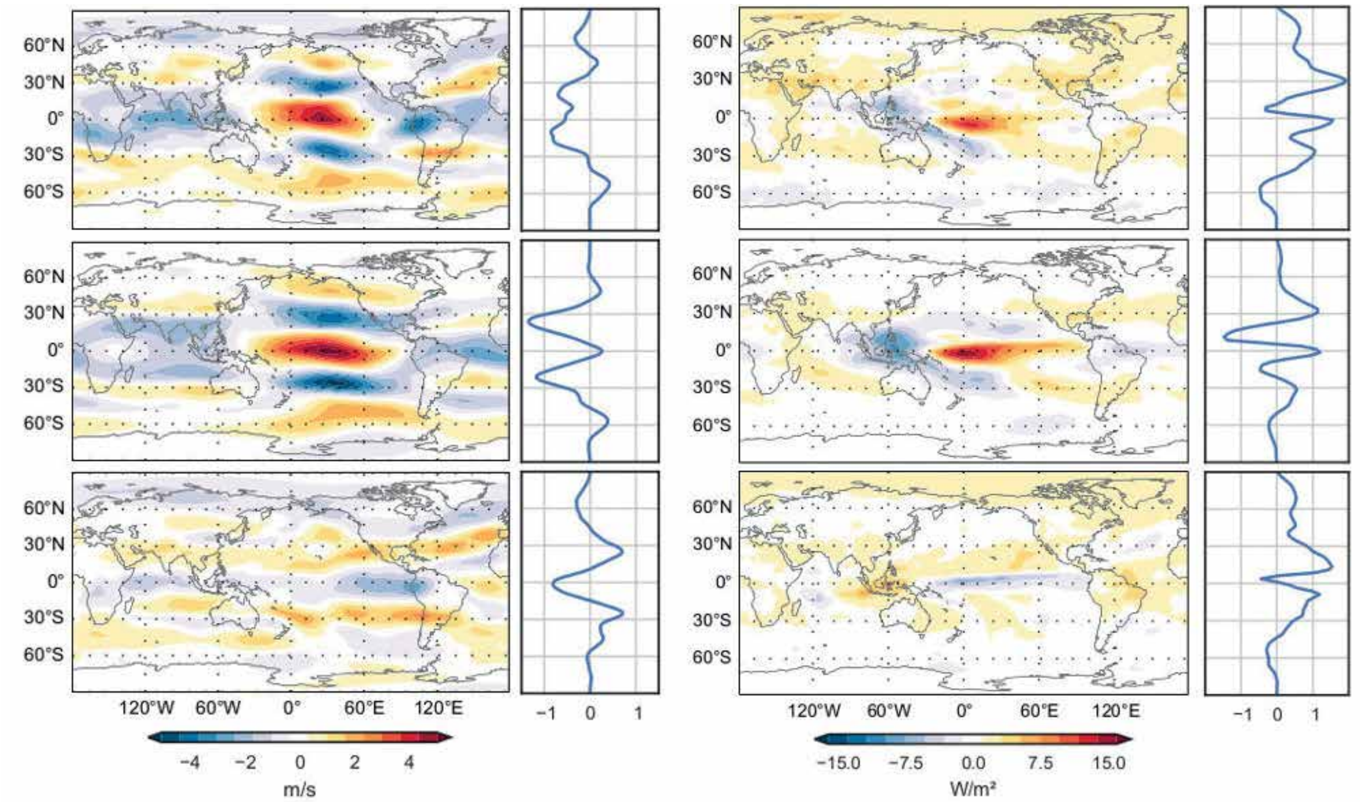

Figure 13: Tropopause height anomalies associated with (a) observed tropical widening, (b) ENSO-like variability, and (c) observed tropical widening with the ENSO signal removed. Figure courtesy: Joy Monteiro.

The first three contributed talks of the session provided both observational and modelling evidence that the width of the tropics has fluctuated in past climates. **Caroline Ummenhofer** used stalagmite records to show that the Australian and Asian Monsoon regions have experienced co-variability in precipitation anomalies for at least the last several thousand years, demonstrating a coherent expansion and contraction of the tropical rain belt on multi-decadal timescales over this period. **Ian Goodwin** described how variability in the width of the tropics in the south western Pacific Ocean contributed to changes in wind and wave patterns in the region over the last millennium, leading to coherent changes in the shape of the Australian coastline as well as likely influencing the migration routes of Polynesian peoples. Finally, **Seok-Woo Son** showed evidence from global climate models that the tropics have widened from the last glacial maximum to the present day.

The majority of the contributed talks in the session focused on understanding changes in tropical width over the recent satellite era (since 1979). Over this period, observational evidence indicates that the tropics have widened by 0.25–3° latitude per decade, which is two to three times larger than most global climate models predict for the same time period. Additionally, at least according to some studies, most of the observed widening has occurred in the Northern Hemisphere, while many climate models indicate that the widening should have been stronger in the Southern Hemisphere. As a result, discussion at the meeting focused on whether the observed trends were radiatively forced (*i.e.*, driven by increasing greenhouse gas levels, anthropogenic aerosols, or stratospheric ozone depletion), or whether they were the result of natural variability in the climate system.

Talks by **Martin Hoerling**, **Christopher Lucas**, and **Joy Monteiro** pointed to the role of natural variability in tropical eastern Pacific sea surface temperatures (the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO)) as an explanation for the very large observed 'trends' in tropical width, especially in the Northern Hemisphere (**Figure 13**). However, **Darryn Waugh** and **Seung-Ki Min** noted that the recent observed expansion of the tropics in Southern Hemisphere summer is strongly linked to stratospheric ozone depletion. **Laura Wilcox** also suggested that aerosols might have had a large impact on tropical width during the mid-20th century. These talks reinforced the idea that tropical expansion driven by radiative forcing over the late 20th

century (as diagnosed by climate models) has been greatly enhanced by natural variability.

Finally, several speakers examined the longitudinal structure of recent observed tropical widening. **Christopher Lucas** and **Joy Monteiro** showed that most of the recent tropical expansion occurred in the Asia-Pacific sector, consistent with the roles of ENSO and the PDO in forcing recent trends. Furthermore, Christopher Lucas showed that while La Niña acts to expand the width of the tropics over the Pacific Ocean, it actually contracts the tropics over North America. In contrast, **Seung-Ki Min** found that the recent expansion of the tropics in Southern Hemisphere summer was largest in the Atlantic and Indian Ocean sectors, rather than in the Pacific Ocean sector.

How and why might the tropical width change in the future?

Aided by the mechanistic understanding and observed widening documented in previous sessions, the attention of the meeting shifted to how the width of the tropics might change in the future, particularly over the 21st century. Keynote speaker **Qiang Fu** provided an overview of the modelling evidence for the future expansion of the tropics. In general, the current generation of global climate models projects an expansion of the tropics over the 21st century at a rate of ~0.2-0.3° latitude per decade, with the largest expansions occurring during the September-November season.

The primary driver of the expansion of the tropics over the 21st century is anticipated to be increasing greenhouse gases and the associated surface warming. But, as noted by **Yongyun Hu** and **Kevin Grise**, the time series' of tropical width do not necessarily follow the global mean surface temperature. Furthermore, Kevin Grise noted that climate models with the largest increase global temperatures in response to increasing CO_2 concentrations do not always widen the tropics the most, suggesting that further research is needed to understand the mechanisms responsible for widening the tropics with increasing greenhouse gas concentrations.

The roles of stratospheric ozone recovery and a reduction in Northern Hemisphere air pollution are also anticipated to have notable impacts on tropical expansion over the 21st century. While Antarctic ozone depletion has contributed to the recent expansion of the tropical belt in the Southern Hemisphere during austral summer, ozone recovery by the mid- to late-21st century is anticipated to counteract future widening due to greenhouse gas increases during this same season. In the Northern Hemisphere, **Robert Allen** showed modelling evidence that decreasing aerosol emissions at mid-latitudes will preferentially warm temperatures there and induce a change in phase of the PDO. The resulting widening of the tropics from aerosol reductions may be of comparable or larger magnitude than that expected from increasing greenhouse gases alone.

Finally, **Qiang Fu** discussed the implications of an expanding tropics over the 21st century, including an expansion of the subtropical dry zone and desertification of marginal lands (**Figure 14**), changes in rainfall patterns at the subtropical margins, and a poleward shift of cloud patterns resulting in climate feedbacks. These ideas naturally led into the fourth and final session of the meeting.

What are the impacts for the oceans, cryosphere, hydrologic cycle, human society, and ecosystems?

The final session of the Chapman Conference focused on the potential impacts of tropical widening on the oceans, cryosphere, hydrologic cycle, human society, and ecosystems. Although these are arguably the most societally-relevant issues relating to the tropical widening phenomenon, from the presentations and discussions at the meeting this topic was clearly the least scientifically developed, with the greatest potential for future contributions.

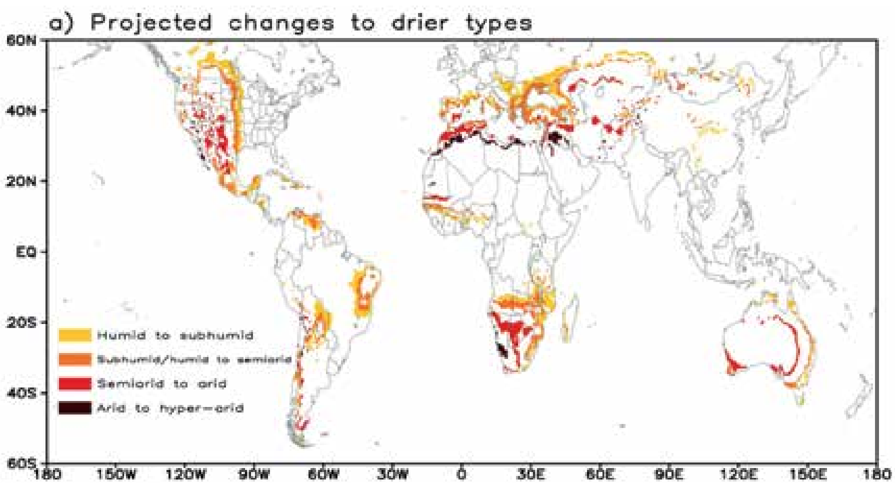

Figure 14: Projected changes in dryland coverage to drier types for 2071-2100 relative to 1961-1990 (under scenario RCP8.5). From Feng and Fu (2013).

Keynote speaker **Kerry Cook** discussed potential tropical width-related impacts that highlighted many of the challenges and gaps in our knowledge. Highlighting the dichotomy between the zonal-mean versus regional changes discussed throughout the meeting, she argued that a regional perspective is crucial for understanding the impacts of tropical widening. She showed that tropical widening impacts will vary by longitude not only because of zonally asymmetric tropical widening but because of the complex nature of society and ecosystems. She also pointed out that from the standpoint of impacts, the rates and seasonality of the changes are often the most important considerations.

One of the major tropical widening impacts considered was a change in the hydrological cycle accompanying changes in the width of the tropics. Reiterating the earlier comments by Qiang Fu, Kerry Cook showed that drought changes can be driven both by changes in precipitation and evaporation. She cited several cases where a robust causal relationship appears to exist between tropical widening and regional hydrological changes. In south eastern Australia and southern Africa during Austral autumn, southward movement by several degrees latitude of the tropical belt and the dry zone has occurred in recent decades. On the other hand, the well-known Sahel drying has not been linked to global-scale tropical widening, and has instead been linked to regional processes.

Another question considered was, "How might an expansion of the tropics affect ecosystems in semi-arid regions?" Natural ecosystems in semi-arid regions (*e.g.* the Middle East, southern Mediterranean) are relatively resilient to climate variations and change because they are located in marginal regions with naturally high variability. However, there is some evidence that subtropical cloud forests, which exist near the edge of the downwelling branches of the Hadley circulation, have been disturbed by recent Hadley cell changes. However, there are conflicting results regarding future predictions.
Finally, the impact of tropical widening on the ocean was discussed. Over 50% of the world's fish catch comes from oceanic upwelling regions, which are areas of high biodiversity. Any changes in the location of the subtropical highs (*e.g.* poleward movement in association with tropical expansion) and associated changes in wind-stress-driven upwelling would have strong implications for fisheries. However, as with other impacts, competing processes such as land-sea temperature contrasts 'regionalize' the response. Thus no definitive link has yet been established between ocean circulation and the Hadley cell changes, although it is quite likely that these linkages do exist (**Gabriela de la Cruz** and **Laifang Li**).

What comes next?

During the concluding discussion session participants tried to summarize the key results of the meeting and to recommend profitable pathways for future research advances and understanding on the topic. Three key conclusions emerged from this discussion:

1. A better connection ought to be made between the global view of the expansion of the tropics (where most research on this topic has centred to date) to the changes in the regional circulations of the tropical and subtropical zones (where the impacts of the expanding tropics are realized).
2. A group should be convened to write a peer-reviewed journal article to document the physical interpretation of each metric for tropical width, to explore how the metrics relate to one another, and to recommend a smaller subset of metrics to be used, consistently and reproducibly, in future studies.
3. The causes of variability in the width of the tropics on decadal timescales remain highly uncertain. Prior to this meeting, the prevailing viewpoint was that recent changes in the width of the tropics have been the direct result of anthropogenic forcing. While the roles of anthropogenic forcings were noted, there was general agreement that coupled variability between the atmosphere and ocean has played a large role in recent changes in the width of the tropics, and this needs to be better understood. As a result of this shift in viewpoint, future research was recommended to address the role of coupled atmosphere-ocean variability in the width of the tropical belt, and how changes in the Hadley circulation might feed back on the general circulation of the ocean.

As Earth's climate continues to warm, the poleward edges of the tropics are projected to continue moving further poleward, while at the same time, being strongly modulated by natural variability. These changes will likely have significant physical, societal, and ecological impacts. The scientific discussions and recommendations laid out by participants in the

Chapman Conference on the "Width of the Tropics" will, we hope, lay the groundwork for research advances and a better understanding of this important topic in the coming years.

References

Feng, S. and Q. Fu, 2013: Expansion of global drylands under a warming climate. *Atmos. Chem. Phys.*, **13**, 10081-10094, doi:10.5194/acp-13-10081-2013.

Davis, S. M. and K. H. Rosenlof, 2012: A Multidiagnostic Intercomparison of Tropical-Width Time Series Using Reanalyses and Satellite Observations. *J. Climate*, **25**, 1061–1078, doi:10.1175/JCLI-D-11-00127.1.

Report on the SPARC Storm Tracks Workshop 24-28 August 2015, Grindelwald, Switzerland

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Storm tracks and jet streams, together with their modes of variability, affect the regional distribution of precipitation, temperature, and wind in the mid-latitudes of both hemispheres. The SPARC workshop on storm tracks, which took place from 24-28 August 2015 in Grindelwald, Switzerland, brought together storm track experts to review recent advances on the dynamics of storm tracks, jets, as well as their modes of variability, and to address key questions related to the regional response to climate change.

Ninety scientists (55 early career scientists) from 16 countries attended the 4.5 day workshop (**Figure 15**), which focused on five themes: storm track processes, coupling to boundaries, coupling with radiation and clouds, climate change, mesoscale processes, and state-of-the-art modelling. The plenary lecture was given by **Brian Hoskins** from Imperial College London entitled 'Storm tracks: a personal perspective'. It provided an overview of storm tracks research over the past 30 years, emphasizing the connections between the large-scale environment, synoptic structure and storm track organization. He also highlighted the challenges of predicting the storm track response to climate change in the presence of opposing impacts from tropical upper tropospheric warming and Arctic surface warming.

Recent advances in storm track processes include a better understanding of seasonal variations of the subtropical jets, their connection to the mid winter minimum (**Hilla Afargan**), and climate change (**Tapio Schneider**). Barotropic and baroclinic components of storm track variability have been defined using observations (**David Thompson**), their feedbacks have been quantified (**Yang Zhang**), and the dynamics can be idealized as a non-linear oscillator model (**Lenka Novak**). Storm tracks are most sensitive to changes in upper-tropospheric baroclinicity in idealized models (**Janni Yuval**) and the tendency

Figure 15: Participants at the SPARC storm tracks workshop held in Switzerland.

of vertically integrated slope of isentropic surfaces is dominated by internal latent heat release (**Thomas Spengler**). The number of storm tracks in idealized models is related to eddy-eddy interactions and energy conversion (**Rei Chemke**). While there has been considerable focus on projecting the jet stream response to different forcings (*e.g.* torque, surface friction, diabatic heating) on to preferred modes of variability there are open questions regarding their physical meaning (**Alan Plumb**). Properly defining the background state using the Energy-Casimir method allows for a more physically-based definition of modes of variability (**John Methven**).

The storm track is influenced by lower, upper, northern, and southern boundaries. Ocean heat fluxes (**Yohai Kaspi**, **Arnaud Czaja**) and circulation (**Francis Codron**), sea surface temperature fronts (**Hisashi Nakamura**, **Funiaki Ogawa**), topography (**Robert Wills**), and tropical waves (**Sukyoung Lee**) shape the intensity and localization of the storm tracks, including cyclogenesis (**Sebastian Schemm**), via changes in stationary waves and baroclinicity. Model simulations suggest recent Arctic sea-ice changes have lead to an equatorward shift of Northern Hemisphere storm tracks (**Clara Deser**, **Steven Feldstein**). The impact of Arctic sea-ice changes is modulated by decadal sea surface temperature variability (**James Screen**). The stratosphere modulates storm tracks during winter via tropopause height changes (**Mark Baldwin**), ozone changes (**Aditi Sheshadri**), and acts as a pathway for ENSO anomalies (**Daniela Domeisen**). The two-way interaction between the troposphere and stratosphere also involves upper troposphere/lower stratosphere jet dynamics and transport (**Gloria Manney**, **Khalil Karami)**, synoptic variability (**Hannah Attard**), and gravity waves (**Claudia Stephan**). Observations and modelling of paleoclimate changes, *e.g.* the last glacial maximum, are a promising emerging research area that will help improve our understanding of storm tracks (**Rodrigo Caballero**, **Paul Hezel**, **Seong-Joong Kim**).

While much of our theoretical understanding of storm tracks is built upon dry dynamics, progress is being made in understanding the coupling between storm tracks, moisture, and clouds. Shortwave cloud radiative effects dominate at the surface whereas longwave effects dominate in the free atmosphere, and both likely affect the strength and location of storm tracks (**Kevin Grise**). Decadal climate variability in the Pacific exhibits clear cloud radiative effect changes that couple with the circulation (**Yen-Ting Hwang**). Simulations with locked cloud and water vapour radiative feedbacks offer a promising approach to disentangle the impact of clouds and water vapour processes on storm tracks and their response to climate changes. The locking method has revealed opposing impacts of short- and longwave cloud radiative effects on the storm track response to global warming (**Paulo Ceppi**, **Aiko Voigt**). Cloud microphysics can also affect the storm track response to climate change (**Neil Tandon**).

There has been considerable progress in our ability to simulate storm tracks using state-of-the-art models. A minimum resolution of approximately 32km over ocean and 16km over topography is required to accurately simulate winter storm tracks and predictions of storm track location are more accurate than storm track intensity (**James Kinter**). Current climate models, which have coarse resolution, exhibit persistent biases in the representation of blocking and this bias does not improve with increased resolution (**Kerstin Hartung**), suggesting there may be limitations to current parameterization schemes. There is also abundant evidence that storm tracks are sensitive to components of parameterized surface stress and comparisons between momentum budgets in climate and numerical weather prediction models may lead to progress (**Ted Shepherd**).

The response of storm tracks to climate change is of significant societal interest. State-of-the-art simulations of the storm tracks response to climate change depends on competing factors including Arctic amplification and tropical upper tropospheric warming (**Tim Woollings**). Models exhibit a small poleward shift and contraction of the storm tracks and global year-round decreases in the number of storms (**Robert Lee**). Models agree that the zonal-mean jet streams will shift poleward. Changes in cyclone frequency have important implications for Mediterranean-type climates that receive their precipitation via wintertime extra-tropical cyclones such as California (**Edmund Chang**). When assessing the forced response, it is important to consider the optimal seasonality for detecting the signal (**Giuseppe Zappa**) because the seasonal cycle of the circulation response to climate change is a function of the seasonality of the forcing and dynamics (**Elizabeth Barnes**). The significance of the forced response can be quantified using unforced variability (**Jingyuan Li**). Thus far ozone has had the largest detectable impact on the Southern Hemisphere storm track via its impact on upper tropospheric/lower stratospheric

Antarctic temperature gradients (**Ed Gerber**).

Our understanding of the response to climate change is built on the results from a hierarchy of models. Idealized aqua planet simulations suggest that storm tracks will shift poleward in response to uniform warming. Recent theoretical progress has focused on the role of potential vorticity mixing (**Jian Lu**) and changes in vertical stability and connection to the Hadley circulation (**Cheikh Mbengue**). Global warming will also change latent heat release (**Ruth Geen**) and in extreme warming scenarios mid-latitude cyclones may develop tropical cyclone characteristics (**Stefan Pfahl**). Changes in wintertime synoptic-scale stationary waves impact regional hydroclimate change over North America via downstream advection by the subtropical jet stream (**Isla Simpson**). During summertime there is a tug of war on stationary wave amplitude in response to carbon dioxide changes due to opposing moist entropy contrasts between land and ocean (**Tiffany Shaw**).

Storm tracks dominate extreme precipitation and wind events in mid-latitudes. A large fraction of extreme precipitation events is associated with warm conveyor belts (**Olivia Martius**). The most damaging winds are often generated by synoptic-scale features on the equatorward side of the cyclone (**Len Shaffrey**) and some windstorms may be related to double Rossby wave breaking (**Gabrielle Messori**). Temperature advection by mid-latitude cyclones leads to a non-Gaussian temperature distribution with cold extremes on the equatorward flank and warm extremes on the poleward flank (**Chaim Garfinkel**). Semi-geostrophic dynamics and a potential vorticity-potential temperature framework offer a convenient framework for tracking Rossby wave packets (**Volkmar Wirth**, **Michael Riemer**). On synoptic scales forecast errors can be introduced due to smoothed potential vorticity gradients and their impact on meridional dispersion (**Ben Harvey**). Recent extreme winters suggest low-frequency waves shape the downstream propagation of synoptic waves, however synoptic waves can subsequently generate new low-frequency anomalies (**Gwendal Rivière**). An understanding of dynamics is crucial for attribution statements to be reliable (**Dann Mitchell**).

Overall, the workshop was very successful. A review paper summarizing storm track dynamics and outstanding research questions discussed during the workshop was submitted in December 2015.

Report on the 8th Atmospheric Limb Workshop

15-17 September 2015, Gothenburg, Sweden

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The 8th International Atmospheric Limb Workshop was held from 15-17 September 2015 at Chalmers Conference Centre, in Gothenburg, Sweden. It was hosted by the Department of Earth and Space Sciences of Chalmers University of Technology. A broad range of topics related to atmospheric limb-sounding observations was covered. The limb workshop series was initiated in Bremen in 2003 and the main focus of the first workshop was on satellite limb-scatter measurements in the ultraviolet (UV) /visible spectral range. In following workshops the scope was broadened, providing a forum for experts to discuss not only limb-scatter measurements, but also occultation and emission measurements in the UV/visible, infrared, and microwave spectral regions. This latest event brought together 70 international scientists, and the programme consisted of 46 oral and 25 poster presentations (for more details, see **www.chalmers.se/en/conference/limb-workshop-2015/Pages/Programme**; most of the presentations are available online).

The workshop was opened by **Donal Murtagh** and **Yasuko Kasai**, who gave a talk to pay tribute to our colleague Jo Urban, who was a leading expert in microwave and sub-millimetre atmospheric observations. He should have been the main organiser of this workshop, but he sadly passed away in August 2014. However, he had already started to think about it, and many of the organisational choices were his. The workshop was organised into five different oral sessions: (1) Instruments: past, current and future missions; (2) Retrieval methods, radiative transfer, tomography and assimilation; Interpretation of science results in the mesosphere (3), in the stratosphere (4) and in the upper troposphere/lower stratosphere (UTLS) (5). In addition, a poster session, allowed for specific discussions and interaction among the attendees. The results presented are summarised in the following subsections.

Past, current, and future limb missions

The scientific sessions started with a talk by **Matthew Deland**, who gave an overview of the OMPS Limb Profiler (LP) instrument aboard the Suomi-NPP spacecraft, which has been making hyperspectral limb-scattering measurements in the UV/visible spectral range since April 2012. He described the version 2 daily ozone product, which is now available. Aerosol extinction and cloud top height are also retrieved from OMPS LP measurements. A next limb profiler instrument will fly on board the JPSS-2 satellite, currently scheduled for launch in 2022. **Patrick Sheese** reported on behalf of Kaley Walker about the current status of the ACE (Atmospheric Chemistry Experiment) satellite mission. After more than 65 000 orbits in 12 years, some degradation in ACE-FTS performance is starting to be seen, but ACE instruments and the satellite are continuing to function nominally and produce good results. There are many retrieved products, which are being used for scientific and validation studies. **Nathaniel Livesey** provided a summary of scientific achievements based on Microwave Limb Sounding (MLS) measurements by the instruments on board the UARS and Aura satellites. He also discussed important related technological advances and plans for future work. **Makoto Suzuki** provided an overview of the SMILES-2 proposal, a follow-up mission to SMILES (Superconducting sub-MIllimetre-wave Limb-Emission Sounder), which operated between late-2009 and mid-2010 on board the International Space Station (ISS). He discussed the scientific requirements of this possible new mission, whose goal would be to observe the diurnal variation of many trace gases in the middle atmosphere. This presentation was complemented by **Philippe Baron**'s talk focusing on stratospheric and mesospheric wind observations from sub-millimetre limb sounding. He presented results from SMILES first and then discussed a simulation study for SMILES-2. A complete overview of the Canadian Atmospheric Tomography System (CATS) was given by **Craig Haley** on behalf of Doug Degenstein. CATS, a UV/visible/near-IR spectrometer, is a follow-up mission to the OSIRIS (Optical Spectrograph and InfraRed Imaging System) instrument, currently in operation on the Odin satellite. He presented the scientific goals and design of the instrument as well as the current mission status. The STEAMR (Stratosphere-Troposphere Exchange And climate Monitor Radiometer) instrument was then described by **Donal Murtagh**. The main target region of this multi-beam sub-millimetre limb sounder is the UTLS, where changes in atmospheric composition have the greatest impact on surface climate. **Linda Megner** gave an invited presentation on the MATS (Mesosphere Airglow/Aerosol Tomography Spectroscopy) instrument. This new Swedish satellite mission, which is currently being prepared for launch in 2018, will focus on mesospheric wave activity and noctilucent clouds (NLCs). **Emmanuel Dekemper** presented the three-channel hyper-spectral imager ALTIUS (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere). The instrument model, in-flight calibration methods, and ozone product were discussed. This presentation was complemented by the following talk by **Fillip Vanhellemont**, also dedicated to ALTIUS, that will be able to measure both in limb-scatter mode and in solar/lunar and stellar/planetary occultation mode. Fililp specifically focused on the occultation measurements, together with the corresponding retrieval strategies.

Retrieval methods, radiative transfer, tomography, and assimilation

The second session was opened by **Larry Gordley**, who talked about the measurement of temperature profiles in the UTLS from star field imaging. He explained this concept, called T-STAR, which can be applied to both balloon and satellite limb observations. **Daniel Zawada** presented recent additions to the SASKTRAN radiative transfer model, which allow it to handle 3D radiative transfer. This is being developed for CATS tomographic retrieval algorithms.

Seth Dueck also reported on SASKTRAN, presenting another improvement to the radiative transfer model which allows it to take into account polarisation for limb-scatter data analysis. **Tomohiro Sato** then discussed the newly developed SMILES retrieval algorithm optimized for ozone isotopic enrichment from spectral measurements. He presented the corresponding validation study and error analysis, and showed the diurnal variation of ozone isotopic enrichment. **Patricia Liebing** described a new algorithm for limb cloud detection from SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) measurements as well as some early results from the algorithm. **Robert Loughman** reported on the new OMPS limb profiler stratospheric aerosol retrieval. He showed preliminary results of aerosol scattering index and extinction coefficient profiles. An overview of OSIRIS tomographic observations was given by **Susanne Benze**, who presented retrieved NLC properties and discussed the potential of tomography for NLC life cycle and satellite intercomparison studies. **Chris Boone** gave a detailed description of the upcoming processing version (v4) for the ACE-FTS retrievals, including a new in-depth analysis of the spectrometer line shape. Thereafter **Alexei Rozanov** gave an invited talk on the recent developments and quality improvements related to the SCIAMACHY limb scatter and solar occultation measurements, including vertical distributions of methane and carbon dioxide, water vapour in the UTLS, mesospheric metals, stratospheric ozone, and stratospheric aerosols. **Landon Rieger** reported on the application of the USask retrieval algorithm, originally used for OSIRIS products, to the OMPS-LP measurements. An overview of an improved OSIRIS nitrogen dioxide retrieval algorithm was then given by **Chris Sioris**. He described the algorithm and presented the results of a validation study for the new nitrogen dioxide product. **Erkki Kyrölä** reported on a comparison study between GOMOS (Global Ozone Monitoring by Occultation of Stars) and OSIRIS ozone and nitrogen dioxide measurements and model simulations using WACCM (Whole Atmosphere Community Climate Model) in specified dynamics (SD) mode. The results provide important new information about the measured data products and indicate probable development targets for future versions of the model. **Steffen Dörner** talked about aerosol extinction from SCIAMACHY measurements in limb geometry. He described recently improved retrieval techniques and showed the results of a comparison study whose goal was to validate the new algorithm. **Janis Pukite** discussed the parameterisation of non-linearity effects of absorption in scattered light observations. He showed how higher order effective light paths can be used to describe radiative transfer. To conclude the session on retrieval methods, **Thomas von Clarmann** discussed the importance of error estimates and proposed an action plan towards unified error reporting.

Limb observations of the mesosphere and lower thermosphere

The session on the mesosphere and lower thermosphere (MLT) started with a presentation by **Yasuko Kasai**. She gave an overview of the scientific results obtained from SMILES observations of middle atmospheric composition. In particular, this instrument provided important information on the diurnal variation of active radical species. **Ole Martin Christensen** talked about NLCs and their background atmosphere, comparing tomographic measurements of NLC properties from OSIRIS with water vapour and temperature observations from SMR (Sub-Millimetre Radiometer). Both instruments are on board the Odin satellite and provide simultaneous high-resolution measurements (see **Figure 16**). **Kristell Pérot** reported on the Odin/SMR nitric oxide observations and showed how they can be used to study the effects of energetic particle precipitation (EPP) on the atmosphere. She presented the first results of a comparison study between SMR measurements and WACCM-SD simulations for a particular winter case affected by a sudden stratospheric warming when nitric oxide produced by EPP in the upper mesosphere was transported down to the stratosphere. **Koen Hendrickx** discussed the observation of 27-day solar cycles in the production and mesospheric descent of EPP-generated nitric oxide, using measurements from the SOFIE (Solar Occultation For Ice Experiment) instrument. The newly developed nitric oxide retrieval algorithm from SCIAMACHY nominal mode limb scans was described by **Stefan Bender**. Continuing on the same theme, **Monika Andersson** gave an invited talk about the effects of EEP. Using measurements from limb-viewing satellite instruments, she showed that EEP is a significant source of mesospheric hydroxyl and a significant cause of ozone loss in the upper atmosphere. This could be an important driver in the Sun-Earth connection. The WACCM-D model, including an implementation of medium energy electron fluxes, can reproduce atmospheric

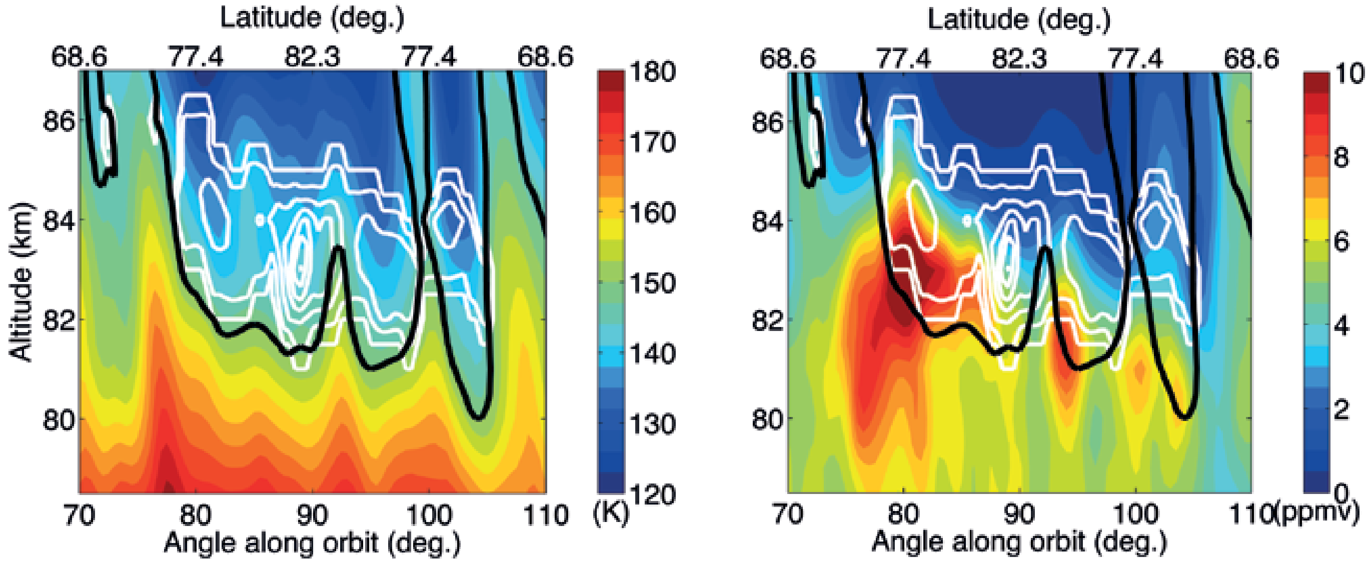

Figure 16: Temperature (left panel) and water vapour mixing ratios (right panel) retrieved from Odin/SMR in tomographic mode compared with the NLC ice mass density simultaneously observed by Odin/OSIRIS in tomographic mode (overlaid white contours, each contour line corresponds to 10ng/m^3). The thick black line indicates the supersaturated area. Figure courtesy: Ole Martin Christensen.

changes due to this mechanism. To conclude this session, **Christian von Savigny** reported on lunar tidal signatures in the MLT region. Such signatures have been identified in terrestrial airglow parameters and, for the first time, in NLC properties. These studies were based on SCIAMACHY and SBUV/2 (Solar Backscatter Ultra-Violet instrument), respectively.

Stratosphere and UTLS

Johanna Tamminen opened the fourth session with an overview of the ESA ozone climate change initiative. The goal of this project is to generate high-quality satellite data sets needed to assess the fate of atmospheric ozone and to better understand links with anthropogenic activities. **Daan Hubert** reported on a ground network-based assessment of fourteen limb and occultation data records, and discussed the uncertainties in a recent satellite ozone profile trend assessment. **Erkki Kyrölä** gave a talk on behalf of Marko Laine, discussing trend analyses of stratospheric ozone and nitrogen dioxide based on OSIRIS and SAGE-II (Stratospheric Aerosol and Gas Experiment II) observations. **Christine Bingen** discussed the characterisation of stratospheric aerosols based on GOMOS measurements, presenting the latest advances in terms of algorithm improvement and development of aerosol time series. **David Flittner** reported on the SAGE III solar occultation instrument, which will be launched in early 2016 to fly aboard the ISS. The main goals of this new mission are to produce stratospheric ozone and aerosol extinction profiles while obtaining data for additional science discoveries. **Krzysztof Wargan** discussed stratospheric ozone during the northern hemisphere winter 2012/2013. NASA's latest reanalysis and operational analyses rely on ozone data from MLS and he showed that there is a need for high resolution and high precision limb ozone observations to ensure the continuity of these projects. **Jeremy Harrison** gave a presentation on hydrogen fluoride, which is important for monitoring the success of the Montreal Protocol. He compared calculations of hydrogen fluoride abundances from the SLIMCAT chemical transport model with observations from the ACE-FTS and HALOE (HALogen Occultation Experiment) limb instruments and discussed its long-term evolution. **Farah Khosrawi** discussed denitrification and polar stratospheric cloud (PSC) occurrence during the Arctic winters of 2009/2010 and 2010/2011 based on a comparison between EMAC simulations and observations from CALIPSO/CALIOP (Cloud Aerosol Lidar with Orthogonal Polarisation), Odin/SMR and Envisat/MIPAS (Michelson Interferometer for Passive Atmospheric Sounding). The last session of the workshop, dedicated to the UTLS region was opened by an invited talk by **Adam Bourassa**, who presented two new prototype limb-scatter instruments that are being developed in Canada. The target of the first, called ALI (Aerosol Limb Imager), is stratospheric aerosols and upper tropospheric clouds. The second instrument, SHOW (Spatial Heterodyne Observations of Water) will be dedicated to the measurement of water vapour in the UTLS. **Vinay Kumar** described a study on the impact of sudden stratospheric warmings on the dynamics of polar and tropical tropopause regions, based on data from the FORMOSAT-3/COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) mission. Finally, the workshop was brought to a close with a presentation by **Ja-Ho Koo**, who reported on a global climatology of trace gases (including hydrocarbons) based on ACE-FTS measurements.

Concluding remarks

The 8th Atmospheric Limb Workshop was a fruitful meeting where experts could discuss limb sounding instruments, retrieval methods, and the interpretation of their results. However, it is noteworthy that most of the presentations were based on past or ageing instruments. Many ideas were presented about concepts for future satellite limb missions, but launch is guaranteed for too few of them. There is an urgent need for follow-up instruments to ensure continuous monitoring of all the atmospheric processes that require vertical profile information with high vertical resolution and global coverage. At the previous limb workshop held in Bremen, Germany in 2013, the young scientist award was a success. We therefore decided to continue this award given to the best presentations by a PhD student or an early career scientist. **Koen Hendrickx**, from Stockholm University, received the award for the best oral presentation ('Observation of 27-day solar cycles in the production and mesospheric descent of EPP-produced NO'). The best poster award went to **Jia Jia**, from the University of Bremen, for her poster entitled 'Sonde validation of improved SCIAMACHY ozone limb data on global scale'. The 9th international limb workshop will be hosted by the University of Saskatchewan, Canada, and is scheduled for summer 2017.

Acknowledgements

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Report on the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2015 Science Workshop

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The IGAC/SPARC Chemistry-Climate Model Initiative (CCMI, **www.met.reading.ac.uk/ccmi**) 2015 Science Workshop was held from 7-9 October 2015, in Frascati, Italy. The workshop started with a joint one-day meeting with AeroCom (**http://aerocom.met.no**) at ESRIN (ESA's Centre for Earth Observations), during which the Aerosol and Chemistry Model Intercomparison Project (AerChemMIP) was introduced to the wider community. The joint meeting was followed by two days of CCMI science presentations hosted at the Italian National Research Council's Institute of Atmospheric Sciences and Climate (CNR-ISAC). Around 130 participants attended. Scientific Steering Committee meetings were held before and after the workshop.

CCMI, AerChemMIP, and CMIP6

The AerChemMIP day was opened by **Simon Pinnock** who provided an overview of ESA activities with relevance to chemistry-climate modeling, such as the ESA Climate Change Initiative (CCI). **Veronika Eyring** introduced the goals and status of the Coupled Model Intercomparison Project (CMIP) the next phase of which (CMIP6) will run from 2016-2020. CMIP6 is designed to make progress in our understanding of how the Earth system responds to climate forcings, what consequences systematic model biases have on climate predictions, and how future climate change can be assessed given climate variability and predictability (Eyring *et al*., 2015). It will build upon a coordinated set of model simulations that include both core experiments and topic-related model intercomparison projects (MIPs).

Bill Collins introduced AerChem-MIP, which was jointly designed by AeroCom and CCMI and officially approved by the CMIP panel in August 2015. It aims to address the question of how different climate forcers have affected climate in the past by focusing on the quantification of the effective radiative forcing of near-term climate forcers (NTCFs), ozone depleting substances (ODSs), and well-mixed greenhouse gases. AerChemMIP will also investigate how future policies on climate, air quality, and land use will affect NTCFs and their climate impacts. CCMI, through its work on process-oriented model evaluation, will provide a crucial basis for the interpretation of model differences found within AerChemMIP. The introduction to AerChemMIP was followed by a presentation about RFMIP, which focuses on the calculation of effective radiative forcing (ERF) from CMIP simulations and better understanding of the model spread in ERF (**Amanda Maycock** and **Steven Ghan** presenting for Piers Forster). Finally, plans for the different forcing databases in support of CMIP6 were discussed, including a new emissions database (**Steve Smith**), two different approaches to generate aerosol forcing databases based on a plume aerosol model (**Stefanie Fiedler**) and a multi-model median from AeroCom models (**Gunnar Myhre**), as well as an update of the existing ozone database using CCMI-1 simulations (**Michaela Hegglin**).

AerChemMIP Science Session

The AerChemMIP science session featured six presentations on a variety of topics. **Massimo Bollasina** discussed model experiments on the Asian monsoon, while **Apostolos Voulgarakis** focused on the temperature response to regional changes in emissions of NTCFs. Both studies highlighted the fact that air pollution (in particular aerosols) can have significant climate effects downstream of the pollution source region. **Cynthia Randles** presented the new MERRA version 2 aerosol reanalysis, pointing out that the successful reproduction of atmospheric aerosol between 1979-present relied heavily on the quality of the forecast model in combination with adequately bias-corrected and quality-controlled observations. **Kevin Bowman** discussed the use of emergent constraints, which exploit correlations between present-day performance of a climate model ensemble and the future response of that ensemble. He presented an example using ozone observations from the TES satellite instrument, showing that the derived constraint for ozone radiative forcing displayed a strong dependency on the chosen model ensemble as well as on the observing system. **Ted Shepherd** highlighted the role of ODSs in radiative forcing with particularly large effects around the tropical tropopause, where feedbacks from ozone and water vapour actually counteracted the expected warming effect from ODSs. Finally, **Claudia Timmreck** introduced VolMIP, a MIP focused on studying the climate response to volcanic aerosol changes in the stratosphere, and the SPARC SSiRC (Stratospheric Sulfur and its Role in Climate) activity, which investigates the entire lifecycle of sulfur in the atmosphere.

CCMI and the TOAR and WMO ozone assessment reports

The following two days of the meeting at CNR started with **Owen Cooper** giving an update on the Tropospheric Ozone Assessment Report (TOAR), an IGAC activity. TOAR will be a comprehensive scientific assessment of tropospheric ozone, covering global distribution and trends from the surface to the tropopause. A major goal of the activity is to generate easily accessible and documented data on a variety of ozone metrics derived from available measurements from different instrument platforms (*in-situ*, air-borne, remote), which will become a valuable data resource for model-measurement comparisons within CCMI. **Paul Newman** presented plans for the 2018 WMO/UNEP Scientific Assessment of Ozone Depletion (see p.9 this newsletter). CCMI's work on process-oriented model evaluation, the understanding of past stratospheric ozone trends, stratosphere-troposphere coupling, as well as future projections of ozone, will be crucial to inform the next WMO/UNEP scientific ozone assessment of the current understanding of past and future stratospheric ozone.

CCMI Modelling Advances

The session on modelling advances was aimed at highlighting the latest progress in the development of chemistry-climate models. **David Plummer** summarized the status of the CCMI data request, emphasizing the importance of a rigorous application of the Climate and Forecast Conventions throughout the MIP process to provide the most concise information possible for all participants. CCMI will have to expand the complexity of the netCDF model output files by adding capabilities to deal with the irregular sampling associated with aircraft and satellite data. It was noted that there was a specific need to balance the size and complexity of the data request with the commitment from modelling groups to provide data. This is to ensure that there is sufficient participation across models to be useful. **Doug Kinnison** provided an overview of improvements made to the WACCM model in preparation for CCMI. In particular, changes to gravity wave parameterizations were made to significantly reduce the lower stratospheric temperature bias found in previous versions. The updated version of WACCM also simulates the temperature response to the Pinatubo volcanic eruption significantly better. In addition, the chemistry has been expanded to include better representation of tropospheric chemistry. **Hidearu Akiyoshi** presented results from the MIROC3.2 nudged CCM, with a specific focus on the stratospheric sudden warming (SSW) event of February 2010. Measurements from SMILES of HCl, ClO, and ozone, as well as N_2O from Aura-MLS, were used to investigate the ability of the model to reproduce the geographical and time evolution of ozone during this SSW. Ozone budget terms inside and outside the vortex were computed, showing negative chemical and positive dynamical forcing inside the vortex. **Olaf Morgenstern** presented results from the NIWA-UKCA model, coupled to the NEMO ocean model. Sensitivity simulations based on REF-C2 using evolving versus fixed ODSs were used to investigate the response of the southern annual mode (SAM) to ODSs. In particular, the use of high-frequency output enabled the analysis of extreme events and the lifetime of SAM anomalies. **Irene Cionni** provided an update of the ESMValTool. Examples of comparisons with observations (temperature, age-of-air, inorganic chlorine, total ozone column, *etc.*) for CCMVal-1, CCMVal-2, and CCMI-1 demonstrate that this tool allows for a quick comparison of different generations of models. The analysis so far indicates that there are no significant improvements compared to CCMVal-2, however, many models were still missing from the comparison. The analysis will be updated regularly as additional model output becomes available.

Tropospheric Chemistry, Dynamics, and Transport

Two talks analysed historical ozone changes in the troposphere. The trends in ozone due to modulations of stratosphere-troposphere exchange and changes in emissions were examined (**Meiyun Lin**). Part of the positive trend in surface ozone over the western US could be explained by sampling issues. Increasing CO and volatile organic compound (VOC) emissions from the US land transportation sector in a model simulation using constraints from urban measurements of the NO_x/CO ratio was shown to better reproduce observed ozone trends over the USA than decreasing NO_x emissions. However, neither case improved the comparison of ozone trends with long-term records from high-altitude sites in Europe (**Sarah Monks**). The CCMI-1 simulations show a large range of OH concentrations, similar to results from ACCMIP (Naik *et al.*, 2013), however, over the last few decades model OH trends were similar. Interestingly, heterogeneous reactions were found to be important in determining OH levels (**Simone Tilmes**). The inter-hemispheric OH ratio model discrepancy and its relation to emissions and chemical reactions was also discussed (**Kazuyuki Miyazaki** presenting for Prabir Patra). CCMI tracer experiments were used to evaluate inter-hemispheric transport times. Simulations could not replicate the inferred northern-to-southern hemisphere transport times from measured tracers (**Clara Orbe**). Finally, the climate mitigation effect of air pollution measures was discussed (**Bill Collins**). Robust temperature reductions were found from measures aimed at reducing methane levels, while only small or no benefit was seen when black carbon measures were included in the simulations.

Observations

Suvarna Fadnavis discussed the role of the Asian Summer Monsoon (ASM) in transporting tropospheric pollution to the stratosphere using the ECAHM5-HAMMOZ model. Variability in ASM drivers (*e.g.* deep convection, sea surface temperature (SST) feedbacks on the Hadley and Brewer-Dobson circulations) as well as the heterogeneity of source distributions lead to significant variability in pollution transport into the stratosphere. **Pieternel Levelt** reviewed current and planned satellite observations of the troposphere, focusing on solar backscatter instruments. The Sentinel-5 Precursor TROPOMI instrument, scheduled for launch in summer 2016, will continue the Aura-OMI heritage of sulfur dioxide, nitrogen dioxide, formaldehyde, volcanic ash, and stratospheric ozone retrievals, with new capabilities for measuring CO, methane, and clouds. The decade-long record from OMI provides trend quality datasets for evaluating and constraining atmospheric models and bottom-up emission inventories. **Johannes Flemming** presented new work using the CAMS interim analysis combined with patchy observations to improve the 3D representation of the global atmospheric chemical state. By assimilating satellite retrievals, the model showed improved fidelity for many tracers as well as aerosols, resolving several known issues in the MACC reanalysis and resulting in a more consistent data set. **Thomas Ryerson** presented an overview of the Atmospheric Tomography (ATom) mission, a 5-year NASA Earth Venture airborne field measurement program starting in 2016. ATom is designed to quantify processing and loss rates for several short-lived climate forcers, including ozone, methane, and black carbon aerosol, during all seasons using *in situ* profile measurements (from 0.2-12km altitude) along latitudinal transects in the Pacific and Atlantic Oceans.

Stratosphere and Stratosphere-Troposphere Coupling

Seok-Woo Son discussed three different dynamical couplings between the stratosphere and troposphere: The ozone hole/southern annular mode, Northern Hemisphere stratospheric warmings/northern annular mode, and quasi-biennial oscillation (QBO)/tropical convection connections. The QBO can have a large impact on tropical convection, with stronger tropical convection and stronger Madden-Julian Oscillation (MJO) during the easterly phase of the QBO. **Chaim Garfinkel** presented a modelling analysis to isolate the role of different factors causing the observed large late-winter cooling trend in the Arctic stratosphere since 1979. Atmospheric forcing from greenhouse gases and ODSs were found to be the main contributors to the ensemble mean cooling, however, significant cooling still occurred when only SSTs were varied. How much of this SST change is itself forced is unclear. Chaim also noted that there was large spread among ensemble members, which raises the question of how much of the observed cooling is attributable. **Andrew Gettelman** described a new prognostic scheme for stratospheric sulfate aerosols, which could be used to better simulate volcanic eruptions in CCMs. A new database for the mass and plume height of SO_2 emissions from volcanic eruptions has been developed from 1850 to the present, and implemented in the newest version (v5) of WACCM. The model shows more aerosol in recent years than both the Vernier *et al.* (2011) and Sato *et al.* (1993) observational data sets, but agrees well with lidar measurements. This would suggest that those data sets are possibly missing aerosol between the tropopause and 15km altitude. **Amanda Maycock** considered the robust model prediction of a strengthened Brewer-Dobson circulation under climate change, which has been attributed to increased wave drag as a result of tropospheric warming. Indeed, an approximately linear connection between the increase in the upward mass flux in the tropical lower stratosphere and warming in the tropical lower troposphere for individual climate models was found. However, the slope of this relationship varies substantially among models. **Ross Salawitch** reported on recent observational constraints on the tropical bromine budget inferred from the CONTRAST and ATTREX aircraft campaigns. A model including oceanic very short-lived substances (VSLS) emissions was able to match the vertical profiles of organic Br species quite well. The measurements of BrO suggest around 7.5pptv Br_y from VSLS is injected into the lowermost stratosphere, which is larger than the 5pptv included in CCMs for CCMI-1 and WMO (2014).

CCMI Breakout Groups

The last part of the meeting was dedicated to three breakout groups on: (1) Specified dynamics (nudged simulations and transport), (2) Stratosphere-troposphere dynamical and chemical coupling, and (3) Chemical and dynamical controls of tropospheric ozone and OH.

The group on specified dynamics explored many of the issues with nudged simulations, where a model is constrained by offline meteorology to reduce the effects of internal atmospheric variability on the simulation of chemical fields. The group proposed a questionnaire be put together to characterize the possible impact of different nudging methods on simulation results. It was mentioned that there may be too many different approaches (*e.g.* different reanalysis datasets used) to attribute differences found across models to particular causes. One of the biggest sensitivities in nudged simulations is that the parameterized convection (along with subsequent transport and scavenging) is very sensitive to how simulations are nudged. In addition, the group discussed the need for a list of diagnostic tracers for transport (such as convective mass fluxes) in CCMI simulations.

The group on stratosphere-troposphere dynamical and chemical coupling discussed various science topics, for example, high latitude stratosphere-troposphere coupling and ozone depletion effects, which have been extensively considered in the literature. There has, however, been less focus on how stratosphere-troposphere coupling and exchange affect tropospheric ozone and thus air quality, as well as radiative forcing. In addition, the coupling of clouds and circulation in the tropics and sub-tropics is a form of stratosphere-troposphere coupling, for example, through the QBO modulation of upper troposphere/lower stratosphere (UTLS) temperatures. To quantify these effects, experiments using idealized stratospheric tracers as diagnostics may be helpful, as would chemical source gases be for investigating chemical budgets. Many of these diagnostics would need to be analyzed in the UTLS in tropopause relative coordinates, which would require instantaneous model output.

The group on chemical and dynamical controls of tropospheric ozone and OH discussed process-based diagnostics in the troposphere, with focus on specific diagnostics for tropospheric OH evaluation. However, these diagnostics may need further development in individual studies using just a few models before becoming part of a subsequent CCMI data request. For comparison with observations, there are a large number of field projects and *in situ* aircraft data, as well as the upcoming TOAR database available.

Update on Directions and Plans of CCMI

The CCMI Scientific Steering Committee (SSC) revisited the timeline and future development of CCMI based on discussions held during the workshop. It was decided to hold the next CCMI workshop in spring 2017, with Météo-France kindly offering to host the meeting in Toulouse, France. In the meantime, CCMI encourages participation from the CCMI community in the 2016 IGAC conference, which will be held from 26-30 September in Breckenridge, Colorado, USA. The timing of the CCMI 2017 Science Workshop will allow for an intensive period of evaluation of the available CCMI-1 simulations to take place during 2016 as well as to work towards publications that will contribute to CCMI-related science questions and in particular to the 2018 WMO/UNEP ozone assessment report. To this end, a joint special issue entitled "Chemistry–Climate Model Initiative (CCMI)" between the online journals ACP/AMT/GMD/ESSD has been set up, and will soon be ready to accept submission of CCMI-related publications.

In order to drive its science forward in a more directed way – a need that emerged from the discussions at the workshop – CCMI has established three working groups. The first focuses on the specified dynamics simulations (led by **Clara Orbe** and **David Plummer**) with the aim of providing consistent information on the differences between model setups and model performance using key metrics. This information will guide the interpretation of results from CCMI studies using the specified dynamics simulations. The second working group focuses on tropospheric ozone and OH (led by **Bryan Duncan**), with the aim of establishing a set of meaningful and observation-based evaluation diagnostics and benchmarking tools. The third working group (led by **David Ferreira** and **Darryn Waugh**) will focus on advancing our understanding of stratosphere-troposphere coupling, in particular the mechanisms by which the ozone hole affected Southern Hemisphere climate in the past, and how ozone hole recovery will affect it in future. This will involve investigating the combined effect of the ozone hole and climate change on Antarctic sea-ice and Southern Ocean circulation. The group has been tasked with coordinating with the SPARC DynVar activity and WCRP CLIVAR core project. More information on the different working groups and potential new action items will be published on the CCMI website.

CCMI-1 science relies heavily on the commitment of the modelling centres to provide simulations and respond to the data request. **Table 7** provides an overview of currently available and planned CCMI-1 simulations, which is testimony to the work that has already been undertaken in support of CCMI. Data users are encouraged to contact modellers directly if they identify that specific data is missing. While a detailed work plan for CCMI-2 will be developed over the coming year, CCMI would like to propose to add two new simulations to the current list of CCMI-1 simulations. These simulations are designed to better understand how different long-lived GHGs affect stratospheric (and also tropospheric) ozone, and whether their effects are additive or non-linear. The new simulations are similar to REF-C2-fODS using REF-C2 specifications (see **Table 8** and Eyring *et al.*, 2013) but run with methane fixed at 1960 levels (REF-C2-fCH4) and nitrous oxide fixed at 1960 levels (REF-C2-fN2O). The simulations will also be used to determine a scaling methodology to produce ozone forcing fields for different emission scenarios that will be used in CMIP6. These forcing data will need to be delivered by October 2016.

It is considered essential to

Table 7: Overview of CCMI-1 simulations that are already finished and publicly accessible (as of 15 December 2015; first number) or planned for delivery by the beginning of July 2016 (second number).

PUBLISHED AT →	BADC															ESGF			
CCMI name → / CCMI Simulation ↓	CCCma	CHASER-MIROC	CNRM-CERFACS	ETH-PMOD	GSFC	IPSL	ECAM / MESSy	MOHC	MRI	NIES	NIWA	U-LAQUILA	UMSLIMCAT	ACCESS	MOCAGE	CESM1-WACCM	CESM1 CAM4	GFDL-CM3	TOTAL
REF-C1	0/3		3	1	1	1/2	2/2	1	0/1	3	3	3	1	0/1	0/1	0/1	3	0/1	19+17
REF-C1SD	0/1	1/2	2		0/1	1	0/4	0/1	1	1					0/1	0/1	1	0/1	7+14
REF-C2 (RCP 6.0)	1	0/3	2	1	1	1/2	0/3	1	1	1	5	3	1	0/1	0/1	0/3	0/3	0/5	17+21
SEN-C1-Emis																			
SEN-C1SD-Emis																	0/1	0/1	0+2
SEN-C1-fEmis												1			0/1			0/4	1+5
SEN-C1SD-fEmis		1/2															0/1	0/1	1+4
SEN-C1-SSI												3	1						4+0
SEN-C2-RCP2.6	1	0/3		1		0/1				1		1						0/1	4+5
SEN-C2- RCP4.5	1	0/3		1		0/1				1		1	1			0/1		0/3	5+6
SEN-C2- RCP8.5	1	0/3		1		0/1				1		1	1			0/1		0/1	5+6
SEN-C2-fODS	0/1	0/3				1				1	2	1	1	0/1		0/1			6+6
SEN-C2-fODS2000						1				1		0/1	1			0/1			3+2
SEN-C2-fGHG	0/1	0/3				1				1	3	1	1	0/1		0/1			7+6
SEN-C2-fEmis		0/3		1								2			0/3			0/3	3+9
SEN-C2-GeoMIP		0/3										2				0/1	0/3		2+7
SEN-C2-SolarTrend		0/3								0/1		3							3+4
SEN-C2-fN2O	Newly proposed simulation																		
SEN-C2-fCH4	Newly proposed simulation																		

Table 8: Newly proposed CCMI-1 simulations using single forcings fixed at 1960 levels for CH_4 (SEN-C2-fCH4) and N_2O (SEN-C2-fN2O).

Name	Period	GHGs	ODSs	SSTs/SICs	Background &Volcanic Aerosol	Solar Variability	VSLS	QBO	Ozone and Aerosol Precursors
SEN-C2-fN2O	1960-2100	Same as in REF-C2 but with N_2O fixed at 1960 levels	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2
SEN-C2-fCH4	1960-2100	Same as in REF-C2 but with CH_4 fixed at 1960 levels	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2	Same as in REF-C2

enhance future communication between the CCMI SSC and the CCMI community, which we aim to achieve by quarterly emails summarizing major news, achievements, problems, and future plans for CCMI. If you are not yet a member and would like to sign up to the general CCMI email list, please send a request to Michaela Hegglin (**m.i.hegglin@reading.ac.uk**). Finally, the CCMI leadership will undergo changes, with Jean-François Lamarque stepping down from being co-chair at the end of 2015. As his successor the CCMI SSC voted in Bryan Duncan (NASA, USA). We also welcome new members to the CCMI SSC: David Plummer (Environment and Climate Change Canada, Canada), Thomas Birner (Colorado State University, USA) and Seok-Woo Son (Seoul National University, South Korea), and would like to thank the outgoing members for their time, commitment, and leadership offered to CCMI.

References

Eyring, V., *et al.*, 2015: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organisation. *Geosci. Model Dev. Discuss.*, **8**, 10539-10583, doi:10.5194/gmdd-8-10539-2015.

Naik, V., *et al.*, 2013: Preindustrial to present-day changes in tropospheric hydroxyl radical and methane lifetime from the Atmospheric Chemistry and Climate Model Intercomparison Project (ACCMIP). *Atmos. Chem. Phys.*, **13**, 5277-5298, doi:10.5194/acp-13-5277-2013.

Sato, M., J.E. Hansen, M.P. McCormick, and J.B. Pollack, 1993: Stratospheric aerosol optical depth, 1850-1990. *J. Geophys. Res.,* **98**, 22987-22994.

Vernier, J.-P., *et al.,* 2011: Major influence of tropical volcanic eruptions on the stratospheric aerosol layer during the last decade. *Geophys. Res. Lett.*, **38**, no. 12, L12807, doi:10.1029/2011GL047563.

SPARC Capacity Development Side Event at the International Conference on Southern Hemisphere Meteorology and Oceanography, 8 October 2015, Santiago, Chile

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During the 11th International Conference on Southern Hemisphere Meteorology and Oceanography held in Santiago, Chile, in October 2015, a 1.5 hour lunchtime side event was organized to present SPARC, its research, and opportunities for early career researchers (ECRs) from developing countries to engage with SPARC.

The side meeting was moderated by **Greg Bodeker** (former SPARC co-chair) who introduced the speakers and provided some insights on how SPARC works as well as ideas on how people might get involved. **David Karoly** presented an overview of SPARC, its objectives, scope, and activities. He also shared a personal story about an Argentinian scientist who contacted him about how he became actively involved in SPARC-related research following the 2nd SPARC General Assembly held in Argentina in 2000. **Larry Thomason** introduced the SPARC SSiRC (Stratospheric Sulfur and its Role in Climate) activity. He also provided some information on the NASA Post-Doctoral Program that is available for ECRs and which requires close collaboration with a NASA scientist. Larry also highlighted the need for ground-based observations to validate the measurements from the upcoming SAGE-III mission as an opportunity for ECR involvement in a satellite mission. Much of the validation is based on collaborative efforts with international groups and NASA would welcome establishing relationships with groups from developing countries making relevant observations. **Margaret Hurwitz** shared her story of how she became involved in SPARC and how SPARC has contributed to the successes she has had during her career. Finally, **Marisol Osman** presented the YESS (Young Earth System Scientists) network which enables ECRs from around the world to connect and share experiences. This network provides resources such as job listings, webinars, and social gatherings at conferences or workshops. More information about YESS can be found at **www.yess-community.org**.

During the discussions, it became clear that most people attending this side event had previously not heard about SPARC or YESS and would not know how best to connect with SPARC and/or its activity leaders, or how to promote their own ideas as a possible new SPARC activity. Most people felt that lack of funding would be the biggest impediment for them to connect to current SPARC science. However, ideas and feedback were provided on how scientists can get involved in SPARC-related research without additional resources. It was mentioned that SPARC and its activities organize a range of workshops and conferences throughout the year and that there are opportunities for scientists from developing countries to apply for travel funding to attend these workshop and conferences. The attendees of the side event were encouraged to register for the SPARC newsletter and to browse the SPARC website for more information and ideas on how to get involved.

Some of the main outcomes and ideas from the discussions during the side event included:

- There is a need for more workshops/conferences in developing countries. One specific idea from Guy Brasseur, chair of the WCRP Joint Scientific Committee, who attended the side meeting, was to have WCRP conferences in developing countries every five years.
- Rather than taking ECRs away from developing countries, *e.g.*, by offering PhD positions in a different country, there is a need to create mentor-mentee programmes that allow ECRs to connect with senior scientists around the world but keeps expertise in the developing country.
- There is a need to create opportunities in developing countries that require ECRs

and researchers on-site, *e.g.* long-term measure-ment programmes.
- There is a need to create opportunities and connect researchers from developing countries with modelling centres to conduct model simulations in close collaboration.
- ECRs need to connect with ECRs in other countries – *e.g.* connect through a network such as YESS.
- There is a clear need for enhanced capacity development in SPARC.

Many ECRs and researchers from developing countries are often not aware of SPARC or opportunities to get involved in SPARC research. This side meeting made it clear that more engagement and similar side events during other conferences/ workshops need to be organized to get more people from developing countries involved in SPARC and to foster more collaborations with ECRs from developing countries.

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SPARC meetings

16-19 February 2016
SPARC workshop Stratospheric Change and its Role in Climate Prediction (SHARP), Berlin, Germany

7-11 March 2016
Workshop on dynamics, transport and chemistry of the UTLS Asian monsoon, Boulder, CO, USA

6-8 April 2016
Workshop on Atmospheric Blocking, Reading, UK

25-28 April 2016
2nd Workshop on Stratospheric Sulfur and its Role in Climate, Potsdam, Germany

16-20 May 2016
Atmospheric Gravity Waves: Sources and Effects on Weather and Climate, State Collage, PA, USA

6-10 June 2016
SPARC DynVar Workshop & S-RIP Meeting (BDC+STC), Helsinki, Finland

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

SPARC-related meetings

5-8 January 2016
International workshop on Exreme Weather in Changing Climate in the Maritime Continent & South-East Asian School on Tropical Atmospheric Science, Bandung, West Java, Indonesia

2-4 March 2016
Global Climate Observation: The Road to the Future, Amsterdam, The Netherlands

5-15 April 2016
Polar Prediction School, Abisko Scientific Research Station, Sweden

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