SPARC
Stratosphere-troposphere Processes And their Role in Climate

newsletter n° 45
July 2015

www.sparc-climate.org

Large volcanic eruptions like the historic eruptions of Krakatoa (1883, see image) and Tambora (1815, see workshop report on page 26) eject large amounts of sulfur species and dust into the atmosphere, including directly into the stratosphere, and thus can have significant impacts on the global climate. Image courtesy: Lithograph by Parker & Coward, Britain, published as Plate 1 in: The eruption of Krakatoa, and subsequent phenomena. Report of the Krakatoa Committee of the Royal Society. London, Trubner & Co., 1888. Licensed under Public Domain via Wikimedia Commons.

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Recent SPARC publication

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

Report on the 22nd Session of the SPARC Scientific Steering Group 13-16 January 2015, Granada, Spain

Johannes Staehelin[1], Joan M. Alexander[2], Neil R.P. Harris[3], and Fiona Tummon[1]

[1]SPARC International Project Office, Zurich, Switzerland, **johannes.staehelin@env.ethz.ch**, [2]Northwest Research Associates, Boulder, CO, USA, [3]University of Cambridge, Cambridge, UK

Neil Harris (SPARC co-chair) opened the meeting, particularly welcoming the new SSG members and thanking the local organizers of the meeting (Bernd Funke and colleagues). **Joan Alexander** (SPARC co-chair) continued with the introduction, emphasizing that one of the main aims of the meeting was to provide input to the new SPARC implementation plan.

Dave Carlson (director of the WCRP (World Climate Research Programme) JPS (Joint Planning Staff)) presented on behalf of Guy Brasseur (new chair of the WCRP JSC (Joint Steering Committee)). Opening with a new vision for WCRP, Dave highlighted WCRP's mission, namely to study and predict Earth system variability and change for use in practical applications of direct relevance and benefit to society. WCRP has so far been very successful in pursuing this goal, but nevertheless needs to remain focused and agile to react to a changing environment. A view of the entire system is required, looking at the atmosphere, ocean, land, and cryosphere through cycles such as energy, water, and trace species (*e.g.* carbon and nitrogen), which link all sub-components of the Earth system. Particular focus will be on analysis and prediction of seasonal to decadal variability, as well as on the regional scale. To do this, all available tools will need to be used in innovative ways: models, observations, and reanalyses, with new aspects such as oceans and chemistry being included in the latter. The six WCRP Grand Challenges will need to serve as focus points and stimulate cooperation among the core projects. Furthermore, there are plenty of opportunities to enhance collaboration with partner programmes (*e.g.* IGBP (International Global Biosphere Programme), GEO (Global Earth Observations), GFCS (Global Framework for Climate Services), and the WWRP (World Weather Research Programme)). He also mentioned that WCRP presently has to cope with budget problems, implying reduced funding available to support WCRP projects.

SPARC activity reports

Each of the SPARC activities had time in plenary to report on their achievements during the past year and their future plans, in particular for the upcoming year.

Gabi Stiller emphasized in her report on WAVAS-2 (Water Vapour Assessment, phase 2), that water vapour is an important greenhouse gas but that open questions still remain concerning transport of this species from the troposphere to the stratosphere. Satellite measurements of water vapour cover the period from 1980 onwards (mostly limb-sounding instruments, but also four nadir-viewing instruments). The comparison of satellite observations with ground-based measurements from hygrometers and microwave radiometers shows that in some regions of the atmosphere satellite observations compare within +/-10%, but problems remain in the UTLS (Upper Troposphere/Lower Stratosphere). A further pair-wise comparison of co-located (zonal mean) satellite data with the long sonde series from Boulder (Colorado, USA) showed that the representativeness of the sonde data from this site remains a problem. The group is aiming to submit a paper about the quality assessment of these data in early summer 2015 and will also work towards putting together a full SPARC report about the activity, including more complete documentation.

Katja Matthes started her presentation about SOLARIS-HEPPA (SOLARIS: Solar influences in SPARC, HEPPA: High Energy Particle Precipitation in the Atmosphere) by highlighting that the effect of solar forcing on climate on the global scale is small, but that on the regional scale it is important in particular seasons. For example, electron particle precipitation (EPP) can have an effect similar in magnitude to the effect of UV solar radiative forcing changes on the North Atlantic Oscillation (NAO) such processes are generally not included in climate models. Further work looking at the simulated response to the solar signal (maximum versus minimum in the 11-year solar cycle) shows that models with interactive chemistry show a realistic temperature response. On the other hand, the CMIP5 (Coupled Model Intercomparison Project, Phase 5) models that used prescribed ozone fields did not show a robust signal in the lower stratosphere, perhaps pointing to the lack of seasonality and full latitudinal coverage in the prescribed ozone dataset. A new recommended dataset is being developed for CMIP6 within the context of the SPARC CCMI activity (see below). SOLARIS-HEPPA is developing solar and EPP forcing datasets for the CMIP6 simulations, and has also proposed a model intercomparison project (MIP), SolarMIP (see **www.wcrp-climate.org/index.php/modelling-wgcm-mip-catalogue/modelling-wgcm-mips** for a full outline of all proposed MIPs), for CMIP6. The group intends to carry out more idealized experiments and is working with CCMI on two scenario runs.

Neil Harris reported some key results from SI2N (SPARC, International Ozone Commission, IGACO (Intergrated Global Atmospheric Chemistry Observations), and NDACC (Network for Detection of Atmospheric Composition Change)). The activity has tackled several issues related to determining long-term ozone profile trends, for example, the propogation of errors and combining trends from multiple data sets. Further issues investigated in this activity were related to combining datasets from multiple sources, which is complicated by the fact that individual instruments may have drifts and errors. The adequate treatment of errors in such cases is complex and the community needs to improve how to assess such uncertainties and their implications for the estimation of long-term trends. In this respect, even though they might not always provide representative records, ground-based networks are absolutely crucial to making accurate estimates of instrument drift. The SI2N activity will be completed in 2015, however, certain questions stemming from the work of this group could evolve into a new SPARC activity. In particular, focus on the tropical tropopause layer (TTL) and the need for a coupled approach to provide a consistent understanding of ozone, temperature, water vapour, and aerosol records in this region.

In his presentation on stratospheric temperature trends **Bill Randel** reviewed the work of the last few years, which has largely focussed on uncertainties in stratospheric temperature observations. This included the homogenisation of radiosonde data and merged satellite datasets, in particular differences between two versions of the merged Stratospheric Sounding Unit (SSU) datasets. Another focus was on reanalyses, including the question of whether they are good enough to use when looking at stratospheric temperature trends, since there are issues related to jumps in the record due to the introduction of different satellite instrument records. Several groups are looking at how to extend the SSU datasets (with AMSU (Advanced Microwave Sounding Unit), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding), or SABER (Sounding of the Atmosphere Using Broadband Emission Radiometry)). The improved homogenised datasets should be carefully compared with most recent models. The group discussed its future, particularly in terms of leadership changes, at a recent workshop held in Victoria, Canada (see page 19 for further details).

Joan Alexander started her presentation on the gravity waves activity by emphasizing the non-linear interaction between gravity waves and stratospheric circulation, with even small changes strongly affecting circulation patterns. Super-pressure balloons have been used to measure gravity wave momentum fluxes for up to nearly an entire season. These data serve as an excellent reference with which models can be evaluated. High resolution ECMWF (European Centre for Medium Range Weather Forecast) data compares spatially very well with the balloon observations, but need to be multiplied by a factor of five to obtain the same range of values. Such high resolution (~10km), gravity wave-permitting models are able to simulate many of the sources of gravity waves, such as tropical convection and winter hemisphere jet sources. These models, however, still suffer from severe circulation biases. The number of articles published about gravity waves and their effect on climate has been growing, and the group would like to write a review paper in 2015 to provide an overview of recent progress. The activity is also organising a dedicated conference 'Atmospheric gravity waves: sources and effects on weather and climate' to be held in May 2016. Similar to the temperature trends activity, the gravity waves group is thinking about the future of the activity, with perhaps a structure similar to SPARC's working group on data assimilation (DAWG; see below) and increased collaboration/

meetings in conjunction with other groups such as DynVar, WCRP's WGNE (Working Group on Numerical Experimentation), CCMI, *etc.*

In her presentation about DynVar (Dynamical Variability) **Elisa Manzini** explained that an effort was begun several years ago to link with CMIP5, in particular to encourage the use of high-top models. Most recently DynVar submitted their own diagnostic MIP to CMIP6. This MIP asks modelling groups to output variables needed for the understanding of dynamical processes. This also has links with the gravity wave activity, through a request for variables used to diagnose gravity wave drag. DynVar has continued to promote the use of high-top models since recent work has shown that stratospheric changes contribute as much to uncertainty in sea-level pressure predictions as tropical upper tropospheric warming and Arctic surface warming. This has implications for uncertainty reduction in estimates of climate sensitivity, sea-ice changes, as well as in decadal predictions. The group has planned several activities, including a workshop on storm tracks contributing to the WCRP grand challenge on 'clouds, circulation, and climate sensitivity' (Grindelwald, Switzerland, August 2015), as well as a DynVar workshop to be held in June 2016 in Helsinki, Finland. The activity has also been working on a publication aiming to produce a consistent definition of sudden stratospheric warmings (SSWs). Enhanced connections with SPARC's CCMI activity (see below) as well as with CLIVAR's (Climate Variability, WCRP core project) climate dynamics panel are likely in the future.

Andrew Charlton-Perez mentioned that SNAP (Stratospheric Network for the Assessment of Predictability) has recently published a review paper in the Quarterly Journal of the Royal Meteorological Society (Tripathi *et al.*, 2014) as well as a paper in Monthly Weather Review, both of which focus on the question: which types of stratospheric dynamic events are influencing tropospheric predictability? Looking at one particular event (a southern hemisphere SSW in 2013), they found that some models can accurately predict the event with a lead time of 10 days, however, once shifting to a lead time of 15 days fewer models were able to predict the event accurately. The activity has strong connections with the WWRP (World Weather Research Programme) S2S (sub-seasonal to seasonal predictions) project and in particular they will be making use of the large operational forecast database this project has established. The activity is relatively small and is currently funded until February 2016, however it is hoped that the momentum built by the group will ensure that activities continue thereafter. SNAP has also been very successful in building a strong community within WCRP, WWRP, and numerical weather prediction centres.

On behalf of Masatomo Fujiwara, **Michaela Hegglin** presented the progress of S-RIP (SPARC Reanalysis Intercomparison Project). The activity has so far looked at nine different reanalyses, and the British Atmospheric Data Centre (BADC) is hosting some of the derived diagnostic products. The first part of their overview report is expected to be published online during 2015. Some first results have appeared in the literature (Mitchell *et al.*, 2014) and these show that the characteristic temperature response to four sources of variability (quasi-biennial oscillation (QBO), solar cycle, El Niño southern oscillation (ENSO), and volcanoes) is remarkably consistent between reanalyses. This is largely because of the observations assimilated, not because of the underlying forecast models used to produce the reanalyses. There is definitely a need and demand for the intercomparison of reanalysis products to be extended into the troposphere, however, this may be taken up sooner by other groups because it is beyond the scope of their initial report.

The SPARC data assimilation working group (DAWG; presented by **Quentin Errera**) provides a forum for data assimilators, data providers, modellers, and users that focus on SPARC themes. Recent work from the group has focussed on using data from OMPS (Ozone Mapping and Profiler Suite), which can be assimilated effectively in both the troposphere and stratosphere. The MERRA-2 (Modern-ERA Retrospective Analysis for Research and Application version 2) dataset show improvements because of a newly-tuned gravity wave drag parameterisation, and has recently been released to the public (see **http://disc.sci.gsfc.nasa.gov/mdisc**). A study group has been established to look at the added value of assimilating chemical data, which at present is not often carried out despite the wealth of atmospheric composition observations available. In a further step the group would like to produce a reanalysis of stratospheric chemical composition, which could be of great use for a number of applications, such as model validation or producing merged datasets. For example, the Canadian Middle Atmosphere Model (CMAM) has been used as a transfer function to remove biases between different datasets to produce a long-term water vapour dataset (Hegglin *et al*., 2014). The DAWG is organising a second joint meeting with S-RIP to be held in Paris, France, from 12-16 October 2015.

The SPARC Data Initiative (SDI) is nearing completion and the group is hoping to complete their final report in 2015. **Susann Tegtmeier** presented an overview of the activity as well as some recent results. Neu *et al*. (2014) analysed ozone in the UTLS region, comparing various limb-sounding instruments with measurements from TES (Tropospheric Emission Spectrometer) and ozonesondes. Largest differences between datasets were found in the tropics, although these differences were reduced with the application of the TES averaging kernels. The SDI data, which are available on the BADC, are ideally suited to model validation and provide a narrowed range of observational uncertainty compared to other data previously used for such purposes. The activity will continue collaboration with CCMI on model validation with SDI products, and would like to contribute to the development of diagnostics for the Earth System Model Validation (ESMVal) tool.

In her summary about SSiRC (Stratospheric Sulfur and its Role in Climate) **Claudia Timmreck** reported that the group is working on a review paper on the sulfur cycle, which will be submitted to Review of Geophysics in mid-2105. SSiRC have asked the question of whether the community is ready to respond to a volcanic eruption in terms of a mechanism for a rapid response measurement campaign. The recent eruption of the Kelud volcano was a first example of such a rapid response campaign, where balloon-borne observations were launched to monitor the volcanic plume. These measurements are vital to understanding microphysical processes occurring within the atmosphere after an eruption and to predict the climate response to volcanic aerosols. Initial results from the Kelud campaign compare well with satellite measurements from CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation). SSiRC is currently working on a proposal for a standard rapid deployment mechanism. Volcanoes are a 'wild card' in future climate projections as well as perhaps in shorter-term predictions, and it is vital that models can robustly simulate the response to volcanic eruptions. At present, there are still large differences among models, for example in the clear-sky radiative response to volcanoes in CMIP5. SSiRC is contributing to VolMIP (part of CMIP6), which will focus on just such issues. In addition, the group is also producing the volcanic forcing for CMIP6.

Michaela Hegglin reported on CCMI (Chemistry Climate Modelling Initiative), a joint activity with IGAC. Many preliminary results from phase one of the activity were presented at the CCMI workshop that took place in Lancaster, UK, in May 2014. Some modelling groups are still working on the current set of simulations (phase-1), whilst others have already completed most simulations and have begun uploading them to the BADC. To do this, the data have had to be 'CMORised' (Climate Model Output Rewriter). Although this is somewhat time consuming, it means the data are fully compatible with the CMIP6 protocol and this will ease any future efforts to submit data, for example, for AerChemMIP. CCMI worked hard during 2014 to develop the AerChemMIP proposal for CMIP6, better defining the key questions addressed by this MIP through participation in the Aspen Global Change Institute workshop and IPCC/WCRP 'lessons learnt' workshop. CCMI will be complementary to AerChemMIP, in particular by meeting the needs of the next ozone assessment. Finally, the activity will also be contributing to CMIP6 through developing updated stratospheric and tropospheric forcing data.

Emerging and new activities

Laura Pan presented ACAM (Atmospheric Composition and the Asian Summer Monsoon), a new joint activity with IGAC. Recent research has shown the importance of the Asian summer monsoon (ASM) in global circulation and its impacts on stratospheric chemistry, a response to the very deep convection that occurs in the region in summer. In turn, it has been suggested that the regional aerosol loading can affect the monsoon leading to a strong feedback of chemistry on climate, which might have large implications for the regional population. Satellite observations continue to provide evidence of the importance of the ASM but very few *in situ* observations are available to better understand local sources of aerosols and trace species, as well as their transport, climate feedbacks, and for the evaluation of chemistry-climate models (CCMs). Carrying out experimental studies in the region is challenging for several reasons, most notably because of infrastructural and geopolitical issues. Building the regional community is expected to be one way to deal with some of these challenges, while working with the international community will help to develop infrastructure and expertise in the region. The second

ACAM workshop was held in Bangkok, Thailand, together with a regional training workshop.

Michael Pitts presented a proposal for a new SPARC activity studying polar stratospheric clouds (PSCs), which largely stemmed from a workshop held in August 2014 in Zurich, Switzerland. After more than two decades of research, much is known about PSCs, but some important questions still remain, particularly how future polar stratospheric cooling may enhance PSC formation and induce ozone losses, and how the relevant processes are represented in CCMs. New observational capabilities have stimulated new research and it was felt it was time to write a review paper to provide a summary of these new developments and to identify remaining research questions. Another new SPARC activity proposal was presented by **Scott Osprey**: QBOi (quasi-biennial oscillation initiative). The main goal of this activity will be to develop a better representation of tropical stratospheric variability in GCMs. Only four CMIP5 models spontaneously produced a QBO and there is large variability in the QBO signal simulated. The reason for this divergent behaviour is not always evident. One common bias is that the simulated QBO never extends low enough, which might have implications for tropical-extratropical teleconnections and influences on tropical cyclone activity. Furthermore, there is no simple set of criteria that guarantees a proper representation of the QBO in models. This feature is, however, one of the longest predictable atmospheric phenomena and being able to simulate it properly has important implications for predictability at seasonal to interannual scales. The group held their first workshop in March (see page 19), which was aimed at better defining the focus of the activity. The group wants to prepare their results in a final report as well as through peer-reviewed papers from individual modelling groups. Both the QBOi and PSC activities were formally accepted as emerging SPARC activities.

IGAC and WCRP bodies

IGAC (International Global Atmospheric Chemistry; presented by **Claire Granier**) has several core activities focused around atmospheric processes including microphysics and deposition, atmospheric chemistry, and emissions (both anthropogenic and natural). Two activities are jointly carried out with SPARC (ACAM and CCMI, see above) and all activities are strongly linked with various aspects of sustainability, such as energy, transportation, urbanization, and climate engineering. IGAC also has regional working groups for China (planned to be extended to include all of Asia) and the Americas. As part of IGBP (International Geosphere-Biosphere Programme), IGAC will be integrated into Future Earth by the beginning of 2016. IGAC views this as a genuine opportunity to enhance connections with laboratory, field, and modelling studies on emissions, atmospheric processes, and atmospheric composition. The Future Earth strategic research agenda, released in December 2014, includes atmospheric chemistry in several of the research priorities. With respect to WCRP, IGAC would like to enhance collaboration with SPARC to address both Future Earth priorities and WCRP Grand Challenges.

Sonia Seneviratne (co-chair) gave an overview of the WCRP core project GEWEX (Global Energy and Water Exchanges). The project focuses on water and energy, and coordinates its research through four panels, of which GDAP (GEWEX Data and Assessments Panel) and GASS (Global Atmospheric System Studies) are probably most relevant to SPARC. GEWEX is also leading two of the grand challenges on water availability and extremes. A future SPARC contribution to the water availability grand challenge would be most welcome, as would collaboration on the extremes grand challenge (this is currently planned through organisation of a joint workshop on blocking and extremes to be held in early 2016). There are also potential connections with SPARC on the issue of predictability of extremes and the role the stratosphere plays in this.

Gerhard Krinner (co-chair) presented the WCRP CliC (Climate and Cryosphere) core project, mentioning that there are many overlaps between the project and the 'Cryosphere' grand challenge (now 'Melting ice' grand challenge). A white paper was recently finalised by the grand challenge team, targeting (1) seasonal, interannual, and longer-term predictability of the polar climate (see also PCPI below); (2) enhanced analysis of model intercomparisons (related to CMIP and the polar arm of the Coordinated Regional Climate Downscaling Experiment (CORDEX)); (3) a focused effort on developing ice-sheet models; and (4) improvement of the representation of permafrost in climate models. CliC has a similar structure to SPARC, with limited lifetime activities, but in addition CliC has a number of working groups that are more permanent (*e.g.* a working group on sea-ice modelling). The Year of Polar Prediction (YOPP) is scheduled for 2017-2018 and this might present the need for further SPARC-CliC collaboration beyond what is already planned within PCPI. The focus group on jet stream linkages with Arctic change may also benefit from collaborations with SPARC.

The Polar Climate Predictability Initiative (PCPI), jointly led by SPARC and CliC, was presented by **Ted Shepherd**. Polar climate predictability cuts across all elements of WCRP and is also a core focus of the WMO Global Integrated Polar Prediction System (GIPPS). The group has been very active and has several activities planned for 2015, including an ISSI workshop on polar feedbacks, a joint workshop with PAGES (Past Global Changes), and is also planning activities for the YOPP. Recent work has focused on emergent constraints, such as the relationship between summertime Arctic sea-ice albedo and seasonal sea-ice retreat in CMIP5 models. Large differences in the way that models simulate this relationship may be one reason for significant differences among models in simulated long-term trends of sea-ice.

Several of the WCRP working groups and councils were presented at the meeting (WGNE – working group on numerical experimentation (**Ayrton Zadra**), WGSIP – working group on seasonal to interannual prediction (**Adam Scaife**), WMAC – WCRP modelling advisory council (**Joan Alexander**), WGCM – working group on coupled modelling (**Veronika Eyring**), and WDAC – WCRP data advisory council (**Kaoru Sato**)). A few highlights relevant to SPARC are mentioned here, but for further details the reader is referred to the JSC meeting report (see page 14). Recent work using data from the WGSIP Climate-system Historical Forecast Project (CHFP) has shown that high-top models provide improved skill in producing seasonal forecasts for the extra-tropics. The CHFP database offers an excellent resource and WGSIP would encourage the community to make further use of these data. WMAC stressed enhanced awareness of needs for model development in all core projects, and asked that meeting organizers consider including a special session on this topic in any events planned. WDAC were very interested in SPARC's S-RIP activity and have made reanalyses one of the main foci of their next meeting to be held later this year. They will also be organizing a special workshop focused on 'Input observations for reanalyses' joint with this meeting. WDAC were also very supportive of SPARC's use of open access journals to present results from its activities and they very much highlighted the need for digital object identifiers (DOIs) for all published datasets. The preparations for CMIP6 are well under way and the WGCM has organised a special issue in Geoscientific Model Development (GMD) that opened in April. SPARC will contribute significantly to CMIP6 in numerous ways, participating in several MIPs (*e.g.* AerChemMIP, VolMIP, SolarMIP, GeoMIP, DA (data assimilation)-MIP, DCPP (decadal prediction), diagnostic MIP), producing forcing data (for ozone, the solar cycle, and aerosols), as well as to the ESMVal model diagnostic tool.

Ted Shepherd and **Mark Baldwin** discussed SPARC's contribution to the WCRP grand challenges. The grand challenge on 'Clouds, Circulation, and Climate Sensitivity' is focused on four key topics, two of which have clear connections with SPARC, namely storm tracks and tropical rain belts. The storm tracks workshop to be held in Grindelwald, Switzerland, in August and organised by SPARC will focus on several questions, for example, why aren't models able to accurately simulate storm tracks? SPARC can contribute as a community to many of the grand challenges, in particular to the 'Extremes' grand challenge through SPARC's expertise in dynamics.

Space agency reports

Claus Zehner started his presentation about the European Space Agency (ESA) by mentioning that ESA currently has a large Earth observation programme, with four types of missions [satellite acronyms are not explicitly spelled out, the reader is referred to each space agency website]: (1) METEOSAT (meteorological satellites), (2) Earth Observation satellites, (3) Copernicus Sentinel missions (more for operational use), and (4) third party missions. At present, three Earth explorers and one Sentinel satellite are in orbit. All data from the Earth Observations missions are being used to develop Essential Climate Variables through ESA's Climate Change Initiative (CCI). From 2009 onwards, several Earth explorers have been launched (GOCE (2009-2013), SMOS (2009-), CryoSat2 (2010-), Swarm (2013-)) and the ADM-aeolus satellite is planned for launch in early 2016). This latter satellite is to focus particularly on tropospheric and stratospheric winds. The Sentinel satellites are to provide long-term space-based monitoring for the COPERNICUS programme. Sentinel 1a launched in April 2014 and Sentinels 1b-d are planned for launch over the next 15 years. Sentinel 5P will be launched in 2016 and Sentinels 4 and 5 will be nadir viewing, mainly aimed to support air quality modelling. In terms of future Earth observation satellites, Earth Explorer 7, with the EarthCARE mission (a joint European-Japanese venture), is planned for launch in

2020 and will monitor biomass. Two missions are currently competing to get on to the Earth Explorer 8 satellite: CarbonSat (greenhouse gas monitoring) and FLEX (chlorophyll observations of terrestrial vegetation).

Ken Jucks presented an update from NASA (National Aeronautics and Space Administration). He started off by focusing on several new NASA missions. The OCO mission has been providing excellent measurements of CO_2 since it's launch in July 2014. The CATS mission is currently on board the International Space Station (ISS) and uses a lidar instrument to provide range-resolved profile measurements of atmospheric aerosols and clouds. SAGE-III will be launched in 2016, also on the ISS, and will hopefully remain operational until at least 2024. The TEMPO mission looking at tropospheric emissions and monitoring of pollution has been selected for Earth Venture, as have two surface carbon cycle missions. OMPS (a joint mission between NASA and NOAA (National Oceanic and Atmospheric Administration) is also currently in orbit and includes both nadir and limb sounders; a follow-on for the SBUV and OSIRIS instruments. OMPS provides ozone profile retrievals as well as aerosol measurements, and is complementary to OSIRIS and the future SAGE-III mission on ISS. NASA will also continue to work on joint polar satellite programmes with NOAA. Several instruments providing data that have been widely used by the SPARC community are on board the Aura EOS satellite, which has been in orbit since 2004. These include HIRDLS, which stopped functioning in 2008; TES, which is still operating despite some technical issues; MLS, which has lost two channels but nevertheless is still functioning well; and OMI, which has a partial blockage of it's field of view but works well otherwise. NASA needs to respond to the needs set out in the decadal survey produced by the US National Research Council, the next of which is due in 2017. At an atmospheric composition workshop last summer, open science questions and the data needed to address them were reviewed. It is hoped that output from this meeting will contribute to the next decadal survey. NASA is also coordinating several sub-orbital activities, one of which is the ATTREX campaign (currently on-going).

Thomas Piekutowski gave an overview and update from the Canadian Space Agency (CSA). Their current missions include MOPITT, OSIRIS, and SciSat satellites, all of which continue operating despite their old age. A new concept being investigated is microsatellite missions, of which two could be of interest to SPARC: CATS (a continuation of OSIRIS) and TICFIRE (to measure thin ice clouds). Development of the SHOW and FIRR instruments is still ongoing and the SHOW instrument might fly on the NASA ER-2 aircraft. This instrument has already been flown successfully in the UTLS region on a balloon. The FIRR instrument will also hopefully fly over the Artic on the Alfred Wegner Institute's Polar6 aircraft.

Makoto Suzuki gave an update on JAXA (Japan Aerospace Exploration Agency) as well as several other Japanese SPARC-related activities. The Japanese Meteorological Agency (JMA) successfully launched the GMS-8 satellite to measure cloud, aerosol, SO_2, biomass burning, and total column ozone. The GOSAT satellite (in orbit since 2009) continues to measure CO_2 and CH_4 columns, with a follow-up satellite, GOSAT-2, planned for launch in 2017. For the moment there are no missions planned for after 2018, even though the last satellites were proposed almost 20 years ago (in 1995). JAXA's Institute of Space and Astronaut Science (ISAS) has a number of atmospheric-related activities. These include the SMILES instrument (a mission run in collaboration with the Japanese National Institute of Communication and Technology), a GPS occultation observing programme, lightning and sprite observations from space with the JEMS/GLIMS instrument on board the ISS, as well as airglow and gravity wave observations from space with the ISS-IMAP/VISI instrument also on board the ISS. ISAS has a small science programme for which a limb-sounding mission application could be made. Despite the small budget, a SMILES-2 proposal would likely have a good chance of getting selected, although the budget for such an instrument might need to be supported by other space agencies and/or in combination with another instrument. A SMILES-2 type of instrument would be able to measure a large number of trace species extending into the upper stratosphere, mesosphere, and lower thermosphere. However, stratospheric chemistry is not a core topic of interest at ISAS (which is largely dynamics focused), therefore it would perhaps be useful to integrate some dynamics observations into the proposal to have a better chance of success.

There is a growing awareness within the community of the looming gap in vertically-resolved atmospheric composition observations (when the Aura MLS instrument stops functioning). **Michelle Santee** briefly gave an overview of the current situation, highlighting the fact that given the very long record of data available, it would be possible to use the data to show which science questions *cannot* be answered without these data. However, this is not an easy issue to address since it requires a strategy that can be used to decide which measurements are important to answer science questions of relevance to society. Considerable work has gone into producing a document that looks into this issue in depth, and which will hopefully be published in a high-impact journal as well as contribute to the US decadal survey. A further idea from the community is to produce a paper focusing on a survey of satellite-based limb sounding observations.

Other presentations

Greg Bodeker discussed SPARC data requirements. This issue was first raised at the 19th session of the SSG in February 2012, and was followed up one year later by a meeting dedicated to this subject held in Frascati, Italy, in February 2013. SPARC activity leaders were asked to summarise their data needs in short documents as input for this meeting. The WMO Global Atmosphere Watch (GAW) has set the provision of real-time data as a high priority and the question was raised as to whether SPARC should look into this issue. SPARC has also provided input for the WMO rolling review of requirements, which is a great opportunity for SPARC to articulate its data needs (SPARC can provide input at any time since it is a rolling document). GAW has a task team on observational requirements with many members currently from data providing institutes, although it might be useful to have some SPARC representation on this task team as well (GAW would certainly welcome this development). NDACC have proposed the idea of a centralised data-processing centre, which would lead to better homogeneity of data from their observational network, however, issues around finding long-term funding to support this are still being discussed. Finally, Greg also mentioned that SPARC could strengthen its connections with the NDACC 'Theory and Analysis' working group.

SPARC items

A significant amount of time was dedicated to discussing the new SPARC implementation plan. This was done by breaking into three sub-groups each of which focused on one of the new SPARC themes, namely 'atmospheric dynamics and predictability', 'chemistry and climate', and 'long-term climate records'. A draft version of the implementation plan was presented at the WCRP JSC meeting in April (see page 14) and the plan will be finalised at the next SPARC SSG meeting.

Thando Ndarana gave a report back on the SPARC Capacity Development workshop held just prior to the SSG meeting in Granada (see the report on page 12). **Bernd Funke** provided a brief report about the local workshop also held prior to the SSG meeting (see page 10 for further details).

Martin Juckes presented an update on the SPARC Data Centre (SDC), which is hosted at the BADC and currently holds about 18TB of data from a wide variety of SPARC activities. Certain datasets are published through the BADC and made publicly available, whilst other datasets are simply hosted at the BADC for the duration of an activity and usually not made public. The BADC has provided technical support for the development of a CMIP-style data protocol for CCMI, whose final data will be published through the ESGF (Earth System Grid Federation). BADC produced automated testing for CCMI output data to ensure that they follow the required conventions. BADC is also very involved in CMIP6 and is working on a data standardisation process for all MIPs. Recently, new computing facilities have been acquired and this will hopefully ensure faster data transfers and the possibility to do data analyses on BADC servers. BADC is also contributing to the ESMVal tool, ESA CCI, and the European COPERNICUS programme.

Johannes Staehelin briefly presented SPARC communication tools, which include the SPARC website, eNews bulletins (issued every two months), biannual newsletter, SPARC annual report, and SPARC science reports. The SPARC Office was tasked with carrying out a WCRP-wide survey on atmospheric dynamics, material of which was presented at the 36th WCRP JSC meeting.

In other news from the SPARC Office, **Thomas Peter** informed the meeting participants that the SPARC Office would be able to stay in Zurich, Switzerland, until the end of 2017. Planning for the next home of the SPARC Office will need to begin this year however, as it would be important to have some sort of overlap between the two offices. This will be discussed in some detail at the next SPARC SSG meeting.

To end off the meeting, Joan Alexander (for **Kaoru Sato**) presented a proposal from the Japanese SPARC community who have offered to host the next SPARC General Assembly. This would likely take place in late 2018 (between September-November) in Kyoto. This proposal will be further discussed at the next SSG meeting to be held in Boulder, USA, from 9-13 November 2015.

Reference List

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Report on the SPARC regional workshop on the 'Role of the stratosphere in climate variability and prediction' 12-13 January 2015, Granada, Spain

Bernd Funke[1], Manuel López-Puertas[1], Lucas Alados-Arboledas[2], Natalia Calvo[3], Emilio Cuevas[4], Manuel Gil Ojeda[5], Luis Gimeno[6]

[1]Instituto de Astrofísica de Andalucía, CSIC, **bernd@iaa.es**, [2]Universidad de Granada, [3]Universidad Complutense de Madrid, [4]Agencia Estatal de Meteorología, AEMET, [5]Instituto Nacional de Técnica Aeroespacial, INTA, [6]Universidad de Vigo

The SPARC regional workshop on the 'Role of the stratosphere in climate variability and prediction' was held from 12-13 January 2015 in the Palacio de la Madraza, Granada, Spain, hosted by the 'Instituto de Astrofísica de Andalucía' (CSIC) and the Universidad de Granada. Following the tradition of holding a 'local' workshop in conjunction with the annual SPARC scientific steering group (SSG) meeting this event brought together 54 international and regional SPARC scientists. The workshop covered a broad range of topics related to the role of the stratosphere in climate variability and prediction, organized in four different sessions: (1) climate-chemistry interactions, (2) observed and modelled changes of the middle atmosphere, (3) stratosphere-troposphere coupling, and (4) seasonal and decadal variability/predictions. Each of the sessions was introduced by two invited overviews, followed by a total of 17 contributed talks. A two-hour poster session with 12 presentations, scheduled on the first day's afternoon, allowed for specific discussions and interaction among researchers.

Climate-chemistry interactions

The role of atmospheric chemistry in climate was addressed by several presentations focusing on polar ozone and chemistry related to polar stratospheric clouds (**Carmen Córdoba-Jabonero**, **Margerita Yela**), stratospheric injections of very short-lived biogenic bromocarbons (**Alfonso Saiz-López**), and the chemical impact of future greenhouse gas (GHG) emissions on Antarctic lower stratospheric ozone (**Natalia Calvo**, invited). Stratospheric chemistry plays a critical role in the perturbation of climate by anthropogenic and natural forcings, but many of the involved processes are still not fully understood. Coupled chemistry-climate models have the potential to reproduce observed climate signals, although the added complexity often leads to increased model spread in intercomparison projects. Additional idealized experiments could help to understand differences between models and to improve the representation of relevant mechanisms in models (**Hauke Schmidt**, invited).

Observed and modelled changes of the middle atmosphere

Long-term observations of chemical and meteorological fields, from the upper troposphere to the lower thermosphere, are key to detecting atmospheric changes and perturbations on different timescales. This session included a large variety of presentations reporting on recent advances in the analysis of ground-based and

Figure 1: Group Picture of the Regional Workshop in Granada, Spain. Photo courtesy: Rolando Garcia (NCAR).

satellite observations, putting them in context with model simulations. Aura MLS satellite observations provide a comprehensive dataset for analysing the impact of pollution on the composition of the upper troposphere/lower stratosphere (**Michelle Santee**, invited). Ground-based FTIR (Fourier Transform Infrared) spectroscopy as carried out at the Izaña Atmospheric Observatory (Canary Islands, Spain) is a key element for the monitoring of long-term variability of GHG and ozone depleting substances (ODS) within the NDACC (Network for the Detection of Atmospheric Composition Change) and TCCON (Total Carbon Column Observing Network) networks (**Omaira García**, invited). Various reanalysis datasets and model data have been used to study the impact of stratospheric sudden warmings (SSWs) on the Brewer-Dobson circulation (BDC) and on the characteristics of the polar vortex (**Laura de la Torre**, **Victor Chavez-Pérez**), as well as to qualitatively diagnose consistent strengthening trends in tropical upwelling and the global BDC (**Marta Ábalos**). Recent satellite observations from ENVISAT MIPAS, ACE FTS, and Aura MLS provide new insights into the stratospheric NO_y budget and its decadal variability (**Bernd Funke**), chemical responses to strong SSW events (**Alessandro Damiani**), seasonal variations of mesospheric water vapour (**Maya García-Comas**), as well as solar cycle variations and trends of CO and CO_2 in the mesosphere/lower thermosphere (MLT) region (**Manuel López-Puertas**). Several presentations also focused on ground-based lidar observations of lower stratospheric aerosol for the study of long-range transport of dust plumes and volcanic eruptions (**Juan Atuña**, **Juan Guerrero-Rascado**). New measurement and retrieval techniques were discussed using examples from the recently developed TEMPERA ground-based microwave radiometer (**Francisco Navas-Guzmán**) and a non-LTE (local thermodynamic equilibrium) retrieval scheme of MLT CO_2 abundances from MIPAS (**Ángel Jurado-Navarro**).

Stratosphere-troposphere coupling

With ten oral and five poster contributions this topic received a lot of attention from the Iberian SPARC community. Many presentations focused on northern hemisphere (NH) polar vortex variability and its relationship to anomalous tropospheric weather regimes.

A new conceptual framework based on mass redistribution provides an explanation for why the surface pattern looks like the northern annular mode (NAM), and why the surface effects are proportional to anomalies in the strength of the polar vortex. However, the reason for tropospheric amplification of pressure anomalies is still not understood (**Mark Baldwin**, invited). The processes associated with coupled stratosphere-troposphere variability are associated with anomalies in the energy of both barotropic and baroclinic waves, and with anomalies in the rates of energy conversions and interactions. The analysis of such anomalies may help for the understanding of underlying mechanisms (**José Castanheira**). Reanalysis data and climate model results have been employed to test the impact of different SSW definitions on tropospheric responses (**Froila Palmeiro**) and to investigate the relationship of Arctic sea-ice loss and vortex weakening events (**Baek-Min Kim**). Several presentations focused on tropospheric precursors of vortex extremes (**Seok-Woo Son**, **Encarnación Serrano Mendoza**, **Adelaida Díaz Durán**) and the influence of the El Niño-Southern Oscillation on blocking precursors (**David Barriopedro**). The central Pacific El Niño stratospheric response was shown to have a significant dependence on stratospheric warming occurrence, providing an interesting example of stratosphere-driven teleconnections (**Maddalen Iza**). The response of the summer North Atlantic

Oscillation (NAO) to future anthropogenic forcing in CMIP5/CCMVal2 models was assessed in order to search for a relationship between model responses and representation of the stratosphere (**Ileana Blade**). Gravity wave (GW) sources and momentum fluxes were analysed with balloon-borne momentum flux measurements and model simulations (**Álvaro de la Cámara**). The transform Eulerian mean (TEM) analysis of GW-resolving global climate model (GCM) results indicates significant coupling between the stratosphere and mesosphere via selective GW filtering (**Kaoru Sato**). Other presentations focused on tropical exchange mechanisms, including a reassessment of tropical widening in reanalysis and GCM data (**Juan Añel**), as well as a climatological study of troposphere-stratosphere mixing using chemical tracer-tracer relationships (**Gaudalupe Sáenz**).

Seasonal and decadal variability/predictions

The prediction of seasonal and decadal variability of NH climate is moving forward quickly. Several examples of longer timescale stratospheric dynamics acting as a source of predictability for the NAO were provided and clear evidence for the importance of the stratosphere in winter seasonal forecasts was shown (**Adam Scaife**, invited). In particular, the solar cycle offers skill to improve quasi-decadal regional climate predictions. It has been demonstrated that the NAO quasi-decadal internal variability mode in CESM-WACCM simulations synchronizes to the solar cycle if solar UV forcing, ozone effects, and atmosphere-ocean coupling are properly taken into account (**Katja Matthes**). Sub-seasonal to decadal forecasting is becoming a well-established operational activity with a solid research base and increasing application in climate services and adaptation. However, there is a need for the generation of action-relevant climate information based on user-demands (**Francisco Doblas-Reyes**, invited). On longer timescales, climate change projections for the 21st century indicate significant future changes in stratospheric and mesospheric temperature trends, which appear to be partly related to stratospheric ozone recovery (**Rolando Garcia**). Total ozone column trends over the Iberian Peninsula have been analysed in the context of ODS-related multi-decadal variability (**Manuel Antón**) and NAO-related changes on multi-annual timescales (**David Mateos**).

Concluding remarks

Overall, the workshop left the impression of a very active and lively SPARC-related science community in the Iberian Peninsula, promoted by a variety of established and emerging research groups. The Granada workshop offered the opportunity not only to interact with international SPARC scientists but also to bring together the various research groups spread over the peninsula. The Mediterranean region is highly sensitive to the impact of both internally- and externally-driven stratospheric variability on northern hemispheric regional climate. Advances in seasonal and decadal predictions are intimately linked to a better understanding of the underlying mechanisms. Iberian SPARC science is actively focusing on these topics.

SPARC Capacity Development Workshop

10-11 January 2015, Granada Spain

Thando Ndarana[1], **Seok-Woo Son**[2], **Fiona Tummon**[3], **and Carolin Arndt**[3]

[1]Council for Scientific and Industrial Research, South Africa, **TNdarana@csir.co.za**, [2]Seoul National University, Seoul, South Korea, [3]SPARC International Project Office, Zurich, Switzerland

During the 5th SPARC General Assembly held in Queenstown, New Zealand, in January 2014, a lunchtime side event was organised to discuss capacity development. At this workshop it became clear that there is a need for more capacity development in SPARC. Later in 2014, the SPARC Office conducted a survey of capacity development needs across the SPARC community. This survey aimed to take stock of the many SPARC-related research activities taking place in different regions, as well as to establish where expertise is lacking. This culminated in a small workshop being organised in Granada, Spain, just prior to the SPARC scientific steering group (SSG) meeting in January 2015. The workshop was aimed at consolidating SPARC's capacity development efforts and to bring together participants from various regions to discuss and develop SPARC's capacity development strategy. The workshop was kindly supported by the World Climate Research Programme (WCRP).

SPARC research has followed a natural evolution moving from tackling the more global issues to regional problems, reflecting a more general evolution of climate science as a whole. Understanding regional issues inherently requires regional knowledge and participation. Workshop participants were thus drawn from nearly all regions of the globe: Asia (**Wen Chen**, **Fahim Khokhar**, **Seok-Woo Son**, **Wenshou Tian**), Europe (**Geir Braathen** (World Meteorological Organisation, WMO), **Boram Lee** (WMO), **Fiona Tummon**), Oceania (**Greg Bodeker**, **Elisabeth Holland** (via skype)), Africa (**Hassan Bencharif**, **Thando Ndarana**, **Jimmy Adegoke**), and North America (**Joan Alexander**). It was essential to ensure as wide a representation as possible so that regional needs could be better understood and incorporated into SPARC's global capacity development strategy.

Using different methods such as a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis, the group identified where SPARC's strengths lie, where challenges might come up, and what opportunities exist for SPARC to partner with existing programmes that carry out capacity development.

It was highlighted that SPARC has an enormous resource in the community of scientists involved in its research. The collegial atmosphere within SPARC as well as the diversity of science means that people from a wide range of backgrounds can easily get involved in SPARC research. To ensure more participation from scientists from developing regions, it is essential to establish why SPARC science is important in these particular regions. The possibility of establishing regional contact points (either small working groups or individuals) was proposed. Through these contact points, SPARC would better be able to assess regional needs and to organise activities focused on particular issues of relevance in a specific region.

The group identified a large number of organisations with whom SPARC could seek partnerships to further its capacity development strategy. These include, for example, various networks between universities in Africa (*e.g.* SASCAL, AUF), regionally focused programmes (*e.g.* APN (Asia), ACCESS (Africa)), or international organisations (*e.g.* ICTP, START, SHADOZ, GFCS). Through these partnerships SPARC could contribute to developing expertise in all regions of the globe, particularly in regions where SPARC science has traditionally not been very strong.

Several concrete ideas were also proposed. These include the development of a mentor-mentee database that could be used to identify mentors and mentees to work on a particular project such as a PhD thesis, or for a more limited time, for example, during a large conference (where a mentor would provide support to a small number of mentees for the limited period of a particular conference). Other activities include the establishment of an early career researchers (ECR) network, and the organisation of training schools/workshops and the collection/publication of the associated learning material online. Progress has already been made in terms of an ECR network, with SPARC making connections with the YESS (Young Earth System Scientists) network. This network is aiming to become a WMO-wide community for ECRs, providing targeted resources such as job listings, webinars, social gatherings at conferences or workshops, and a means of communications across disciplines. More information about the community and how to join can be found on: **www.yess-community.org**.

To ensure success, SPARC will need to ensure that its capacity development strategy and all associated activities have a long-term vision. SPARC will need to endeavour to create 'life-long' opportunities and to work towards the growth of expertise such that a 'critical mass' is established in all regions, ensuring longevity of capacity development efforts as well as continuation of SPARC science and leadership. Two, or possibly more, members of the SSG will need to be responsible for SPARC capacity development efforts, as well as the monitoring and evaluation of these activities. Incentives for capacity development in the SPARC community could be implemented, for example through recognition in the SPARC newsletter or the opportunity to present work at SPARC conferences.

SPARC's capacity development strategy is currently being developed and will be published before the end of 2015, in parallel with SPARC's new science implementation plan. The community is welcome to participate in this development and are asked to contact the SPARC Office (**office@sparc-climate.org**) to get involved. SPARC is also working in collaboration with WCRP to ensure that SPARC's strategy is inline with WCRP's own capacity development strategy, which is also currently being put together. This is to ensure efficient partnership and to share experiences with other core projects and grand challenges.

Acknowledgements

SPARC would like to warmly thank WCRP for providing travel support for several participants of the workshop, without whom the workshop wouldn't have been as successful as it was.

Report on the 36th session of the WCRP JSC

8-10 April 2015, Geneva, Switzerland

Fiona Tummon[1], Joan M. Alexander[2], Neil R.P. Harris[3], and Johannes Staehelin[1]

[1]SPARC International Project Office, Zurich, Switzerland, **fiona.tummon@env.ethz.ch**, [2]Northwest Research Associates, Boulder, CO, USA, [3]University of Cambridge, Cambridge, UK

The 36th meeting of the World Climate Research Programme (WCRP) Joint Scientific Committee (JSC) took place in Geneva, Switzerland from 8-10 April 2015. Held at the World Meteorological Organization (WMO) headquarters, the meeting was an opportunity for several representatives from various WMO programmes to join the meeting. It was also a forward-looking meeting, focused on the future of the WCRP.

Guy Brasseur, new chair of the WCRP JSC, opened the first session by presenting his vision for WCRP. This included 12 vision statements aimed at providing a robust framework to ensure WCRP's success in the coming years. They focused on supporting advanced research dealing with the dynamics, physics, and chemistry of the Earth system, and communicating this research through an active interface between WCRP and climate information users. This involves the continued support of the four core projects, while ensuring that their science serves WCRP's overall mission as well as the success of the Grand Challenges. Guy talked about the introduction of several new research themes, topics that were highlighted during a WCRP/IPCC (Intergovernmental Panel on Climate Change) 'lessons learnt' workshop held in Bern, Switzerland, in 2014. They include 'modes of climate variability and seasonal to decadal predictions'; 'dynamics, physics, and biogeochemistry of the ocean'; 'biogeochemical cycles of carbon, nitrogen, and other species'; 'aerosols, clouds, and atmospheric chemistry'; and 'urbanisation and climate change'. The vision statements also targeted several other aspects such as simplifying the WCRP structure to ensure more efficient functioning with clear objectives that lead to noticeable deliverables, enhancing the regional presence of WCRP, and developing a sustained WCRP capacity development programme as well as a long-term funding strategy. These latter issues were brought up as possible topics that small working groups, lead by JSC members, could focus on.

Some of these points were also echoed in **Roberta Boscolo**'s (WCRP Joint Planning Staff) presentation about WCRP communication and outreach. A particular point in common was the need to develop a new WCRP public relations approach, which could also be the topic of focus of a mini-JSC working group. The two-way communication between WCRP and climate information users was highlighted as a vital way of ensuring WCRP science is relevant to society and used in the right manner.

Sponsor and Partner Programme Reports

Along with several new faces at WCRP, a number of WCRP sponsors have also seen changes. **Vladimir Ryabinin**, previous SPARC liaison, is now executive secretary at the Intergovernmental Oceanographic Commission (IOC). The IOC is working hard on restoring support to previous levels, but will continue with it's work as WCRP sponsor, including its guidance, regardless of the funding situation. There is obviously strong connection between the IOC and WCRP, particularly through CLIVAR (Climate and Ocean: Variability, Predictability and Change; WCRP core project), however, international ocean research might be improved through better links between the IOC, SCOR (Scientific Committee on Ocean Research), Future Earth, and WCRP.

Heide Hackmann, the new director of ICSU (International Council for Science), spent a good deal of her presentation discussing Future Earth, which has complementary strengths to WCRP (see the Future Earth website: **www.futureearth.org**). ICSU is just one of several members of the Future Earth governing council; other members include UNEP (United Nations Environment Programme), UNESCO (United Nations Educational, Scientific, and Cultural Organization), ISSC (International Social Science Council), WMO (World Meteorological Organization), the Belmont Forum, United Nations University, and the Sustainable Development Solutions Network. Future Earth itself also has a new executive director (**Paul Shrivastava**) and as of 2015 has a globally distributed secretariat with regional hubs in various locations. The programme has recently put together their 2025 vision, which covers eight grand societal challenges, however, the exact structure of the organisation and its activities is yet to be defined. In particular the integration of IGBP (International Geosphere-Biosphere Programme) projects such as IGAC (International Global Atmospheric Chemistry) and PAGES (Past Global Changes) is being discussed (**Sybil Seitzinger**, executive director IGBP). These projects are to be integrated into Future Earth by the end of 2015 but have also continued to engage with WCRP to ensure that existing synergies between projects are maintained and expanded upon. For example, **Thorsten Kiefer**, PAGES executive director, signed a memorandum of understanding with WCRP at the JSC meeting.

WMO, the third WCRP sponsor, remains entirely supportive of WCRP and continues also to endorse WCRP's partnership with Future Earth (**Jerry Lengoasa**). Now that the Future Earth advisory council is established, it was suggested that the WCRP JSC engage with them to ensure effective inter-project collaboration. In the partnership with Future Earth, as well as with many other bodies, WCRP is seen as a research leader, producing excellent informative science. The necessity of such partnerships was highlighted on many occasions, for example with GFCS (Global Framework for Climate Services), GCOS (Global Climate Observing System; **Carolin Richter**), and GEO (Group on Earth Observations; **Barbara Ryan**).

An update on the WMO World Weather Research Programme (WWRP; **Sarah Jones**) highlighted many areas of commonality between the WCRP and WWRP. These include high impact weather, water (in terms of disaster risk reduction and resource management), urbanization, as well as evolving technologies, a topic which covers climate engineering. The WWRP aims at seamless prediction of the Earth system on scales ranging from minutes to months, covering the shorter timescales while WCRP focuses on the longer timescales ranging from months to centuries. Projects such as the sub-seasonal to seasonal (S2S) project and the polar prediction project (PPP) thus provide excellent opportunities for the weather and climate communities within WWRP and WCRP to work together. There are further potential links through topics such as quantifying uncertainty, data assimilation, and the WCRP grand challenges.

Implementation of the WCRP Grand Challenges

The future direction of WCRP science was extensively discussed during sessions about the Grand Challenges and the core projects. The Grand Challenges are seen as flagship activities each focusing on a particular question that is at the same time scientifically challenging and societally relevant, and is answerable on a 5-10 year timescale. The Grand Challenges are at various stages, some already starting to produce first results, whilst others are still refining their focus, activities, and structure. The Polar Climate Predictability Initiative (PCPI), a part of the Grand Challenge on Melting Ice (previously the cryosphere Grand Challenge; **Greg Flato**) and which SPARC is jointly leading, has been very active in its development. The initiative has organized a number of activities for the next year, including a 'polar amplification' session at the IUGG conference in Prague, Czech Republic, in July, and a session on the 'role of jets and non-zonal circulation in the Antarctic' at the 2015 ICSHMO (International Conference on Southern Hemisphere Meteorology and Oceanography) in Santiago, Chile, in October. PCPI will also participate in the Year of Polar Prediction (YOPP), which is being organized from mid-2017 to mid-2019.

SPARC is perhaps most involved in the Grand Challenge on 'Clouds, Circulation, and Climate Sensitivity' (**Bjorn Stevens**). A recent article in Nature (Bony *et al.*, 2015) highlighted the four questions this Grand Challenge is aiming to address: What role does convection play in cloud feedbacks? What controls the position, strength, and variability of storm tracks? What controls the position, strength, and variability of the tropical rain belts? What role does convective aggregation play in climate? Separate workshops have been organized around each of these questions, with SPARC organizing the workshop on storm tracks to be held in Grindelwald, Switzerland, in August 2015. This Grand Challenge has especially strong links with the Grand Challenge on Extremes, and SPARC is also helping to organize a related workshop on 'Blocking and Extremes' to be held in Reading, UK, in March/April 2016. The Grand Challenge has already produced a number of high-profile papers and is also coordinating various research activities, including model intercomparison studies (participating in CMIP6) as well as field experiments. Further details about the Grand Challenges can be found on the WCRP website: **wcrp-climate.org/grand-challenges**.

Core Project Reports

Joan Alexander presented the SPARC report, which had a large focus on the new implementation plan, which is currently being developed. The new implementation plan highlights three themes: 'atmospheric dynamics and predictability', 'chemistry and climate', and 'long-term records for climate understanding', around which SPARC's activities are centred. Furthermore, a number of emerging activities were mentioned, as well as how all these activities link with other programmes, grand challenges, and working groups. A few of the possible new research topics to be considered within SPARC were presented. These include a focus on teleconnections, predictability, aerosol-cloud-chemistry interactions, stratosphere-troposphere exchange of ozone and water vapour in a changing climate, and the development of quantitative methods to define the consequences of measurement gaps. Examples of questions arising from these topics are: How well are teleconnections represented in observations and models? And do we understand the mechanisms behind them? What are the limits on predictability due to internal variability (on timescales ranging from seasonal to decadal to centennial)? What are the dynamics behind unprecedented (unpredictable) events? What are the implications of changes in stratosphere-troposphere exchange on air quality and radiative forcing? The new implementation plan will continue to be developed throughout the year and will be finalised at the November 2015 meeting of SPARC's scientific steering group.

The reports on the three other core projects emphasised several aspects of interest. CLIVAR (presented by **Lisa Alexander**) is re-organizing its structure to some extent, with the development of limited-lifetime research foci that cut-across their long-standing panels. The project is planning a large CLIVAR Open Science Conference to be held in Qingdao, China, in September 2016. In conjunction with the conference will be a dedicated early career scientist symposium and a one-day meeting with regional stakeholders. Similar to CLIVAR, CliC (Climate and Cryosphere; presented by **Greg Flato**) is also moving towards having more limited-lifetime targeted activities in addition to its various working groups and fora. With increased attention on modelling, CliC has recently established two modelling fora focused on sea-ice and permafrost and is contributing to CMIP6 through three model intercomparison projects (Ice sheet MIP, snow in Earth system models – within the land surface MIP, and the diagnostic sea-ice MIP). Since many modelling centres are further developing their models for CMIP6, it was suggested that this was an ideal opportunity to ensure that the best cryosphere models get integrated into global models. GEWEX (Global Energy and Water Cycle Experiment; presented by **Sonia Seneviratne**) is also contributing to CMIP6 through the HighResMIP and MIPs focused on land surface features (land-use change, soil moisture, *etc*.). This is the first time the project is strongly involved in the CMIP process, and, similar to CliC indicates a renewed focus on modelling. GEWEX has several activities that cut-across WCRP, including working with SPARC on the Extremes Grand Challenge (which GEWEX is leading) and with CLIVAR on a joint monsoon panel.

CORDEX (Coordinated Regional Downscaling Experiment; presented by **Bill Gutowski**) has benefited significantly from the establishment of a dedicated project office hosted by the Swedish Meteorology and Hydrology Institute as well as a scientific advisory team, who perform a similar role to SPARC's scientific steering group. Because of its inherent regional focus, CORDEX is trying to make strong links with the vulnerability, impacts, and adaptation (VIA) community. One of their main challenges, besides improving our understanding of regional climate and our prediction of it, is communicating relevant information to users. A CORDEX conference is being organised in May 2016 to be held in Stockholm, Sweden.

WCRP Working Groups and Advisory Councils

Reports on the various WCRP working groups emphasised the enormous breadth of science going on within the programme. The main activity of the working group on coupled modelling (WGCM; **Catherine Senior**) is the organisation and implementation of CMIP6. The endorsement of MIPs has been finalised (all MIPs with more than eight modelling groups willing to participate have been endorsed), and modelling groups will start running simulations from 2016 onwards, once the required forcing datasets have been produced. The WGCM infrastructure panel has also been working hard on technical issues such as CMIP documentation, common calendars and grids, data standards and conventions, as well as open access to data. The working group on seasonal to interannual prediction (WGSIP; **Adam Scaife**) has produced a database of seasonal forecasts, equivalent to the CMIP database, and they are working on establishing a similar database for decadal predictions as well. These databases provide an excellent resource to investigate various topics, three of which are the focus of new WGSIP projects: teleconnections, model drift, and snow cover, the former two of which overlap clearly with SPARC expertise. The working group has strong links with GFCS, but would like to extend them further to ensure efficient collaboration between researchers and forecasting centres. The working group on numerical experimentation (WGNE; **Jean-Noël Thépaut**) also has a number of interesting coordinated projects, for example, Transpose-AMIP (testing climate models in weather mode) and a project looking into the effect of aerosols on weather forecasts, which serve the group's aim of developing and resolving short-comings in atmospheric circulation models. There are also links between WGNE's surface drag project and SPARC's gravity wave activity and the emerging quasi-biennial oscillation initiative. The working group on regional climate (WGRC; **Bruce Hewitson**), carried out a survey of the VIA community on CMIP outputs with the aim of providing feedback to enable a better design of CMIP6. The survey showed that temperature and precipitation were the most requested variables, however, the data were not available at an adequate resolution and most users carried out their own 'downscaling'. Furthermore, it was found that most users relied on data from a single model. The survey highlighted a clear need to better communicate how data can be used and for regional climate information to be easily available to the VIA community. The working group is focused on coordinating regional climate research within WCRP, providing links between projects, and also serving as a two-way conduit between WCRP and institutions coordinating climate services.

The WCRP modelling advisory council (WMAC; **Christian Jakob**) has organized its first model development training school, which received an enormous number of applications. The advisory council would like to ensure that material from such training schools is made available afterwards, for example through web hosting of lectures, *etc.* It also selected the first winner of the joint WCRP/WWRP model development prize. The annual prize will be continued in 2015, open for nominations as of July, with a deadline of 1 October. WDAC would also like to form a small team to investigate the hosting of model diagnostic tools for use by the wider WCRP community. In this respect, there is a need to coordinate with the WCRP data advisory council (WDAC; **Otis Brown**), to ensure that adequate data is easily available to test and evaluate models. In this respect the Obs4MIPs database provides an excellent resource for a wide range of observations, ranging from satellite to aircraft and ground-based measurements.

Parallel Discussion Sessions

To provide room for in-depth discussion six break-out sessions were organised to focus on the topics of urban regions, climate information, capacity development, the planet data initiative, decadal aspects across WCRP, as well as funding and structure within WCRP. Two sessions were held in parallel each time, with the main points then presented in a final plenary session. Presenting the report from the 'Urban Issues and Climate' breakout group, **Jens Christensen** described a few of the complexities related to this topic. The urban system has numerous flows that need to be considered: energy, water, material, and transport. They are affected by climate but in turn can also affect the climate as well as the air quality in surrounding regions. There are a huge variety of interdependencies at a number of levels that need to be taken into account when providing climate information at the city level. The science related to this lies within the mandate of the WGRC and particular urban areas could provide an ideal test bed for determining how best to 'distil' the required climate information. This would also fit well within the topic of climate information, presented by **Clare Goodess**. Discussion around the climate information Grand Challenge focused both on the science as well as whether this issue indeed fits into the grand challenge framework at all. It was agreed that the topic was perhaps not ripe for grand challenge status at present, but the steering group would document what has already been achieved and the WGRC would move forward with two tasks: consulting further with external agencies about user-driven science and interacting across WCRP projects and grand challenges.

There is a great need for more focus on decadal aspects across WCRP (**Adam Scaife**). It was clear that end-user expectations regarding seasonal and decadal climate information need to be well managed, particularly in terms of how uncertainties are communicated. Decadal predictions are still in their infancy compared to seasonal predictions, in part because of the relatively limited observational record. Such predictions are, however, vital to policy makers and could provide an invaluable contribution to GFCS, although no official mechanism yet exists for this transfer of information. Research needs to address coupling, variability, and contributions to decadal predictability from all components of the Earth system to improve our understanding of the mechanisms driving decadal variability and predictability.

The breakout session on 'Planet Data' focused on an initiative to develop Earth system reanalyses covering atmosphere, ocean, land surfaces, as well as biogeochemical cycles (**Dave Carlson**). The discussion came to the conclusion that it was perhaps too early to start developing such products since there is not yet the need from the modelling community for integrated biogeochemical analysis products. The matter will need to be reviewed within WDAC and could go through Obs4MIPs. Dave also presented the summary of the discussion about WCRP funding, which focused on trying to secure long-term sustainable funding for the programme. Local JSC members as well as scientists from the grand challenges and core projects could help secure contributions from their countries through letters to the corresponding government agencies. The approach will need to be targeted and carried out across the community based on existing connections as well as new strategic opportunities.

The 'Capacity Development' breakout session (presented by **Thando Ndarana**) was initiated from the SPARC Capacity Development workshop held in January 2015 (see page 12) and was aimed at bringing this issue to the WCRP level. As emphasized many times during the meeting, one of the key points was that a WCRP-wide strategy would need to focus on the regional level. The strategy will also need to build on existing community-driven initiatives, work closely with a wide range of partner organisations (*e.g.* START, APN, IAI, ICTP, *etc.*), and have a long-term vision, *i.e.* moving away from event-based activities towards sustained and longer-terms impacts. A priority will be to establish concrete activities that can be tracked and evaluated. It was recommended that a sub-group with leadership from JSC members be formed to help develop the strategy.

Just prior to closing the session, **Gaby Langendijk** (WCRP intern) presented an innovative estimate of the 'greenest' location for a JSC meeting by making estimates of carbon dioxide emissions from travel. This stems from a recent working paper from the Tyndall Climate Centre (Le Quéré *et al.*, 2015) highlighting the contradiction of climate scientists flying so much to attend conferences and meetings. Lowest emissions were seen for a nodal meeting, where groups of people meet in a central location of various regions and then communicate altogether using high quality teleconference facilities.

The meeting was officially closed by **Guy Brasseur** who thanked all participants for their active contributions to the meeting.

All presentations from the meeting are available online at: **www.wcrp-climate.org/jsc36-agenda** (by clicking on the links in the agenda).

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Report on the 1st QBO Modelling and Reanalyses Workshop, 16-18 March 2015, Victoria, BC, Canada

James Anstey[1], Kevin Hamilton[2], Scott Osprey[3], Neal Butchart[4], Lesley Gray[3]

[1]University of Oxford, UK, **james.anstey@physics.ox.ac.uk**, [2]International Pacific Research Center, University of Hawaii, USA, [3]National Centre for Atmospheric Science, University of Oxford, UK, [4]Met Office Hadley Centre, UK

The large-scale circulation in the tropical stratosphere is one of the most predictable aspects of the global climate system. Interannual variability of the zonal-mean circulation here is overwhelmingly dominated by the Quasi-Biennial Oscillaion (QBO; for other acronyms see glossary at end), a long-period (~2.4 years) oscillation of winds and temperatures that is more predictable than any other known atmospheric phenomenon (*e.g.* Hoskins, 2013). Because of the QBO's high predictability, accurate modelling and improved understanding of its teleconnections – the influence it is believed to exert on other regions of the atmosphere – may help improve the quality of seasonal predictions and contribute to improved representation of natural variability in climate models. Yet the QBO is currently not simulated at all by many stratosphere-resolving GCMs. It is also unclear whether GCMs that do exhibit QBOs in the zonal-mean winds do so for realistic reasons: do they accurately represent the driving processes of the real QBO? Models can be validated through comparisons to observations and reanalyses, but QBOs in reanalyses are themselves subject to uncertainties in the underlying forecast model and the manner in which observations are assimilated.

The 1st QBO Modelling and Reanalyses Workshop, held from 16-18 March 2015 in Victoria, BC, Canada, was motivated by the need to address these issues. 32 scientists from Europe, the USA, Canada, and Japan participated (**Figure 2**), and SPARC provided travel support for early-career researchers. The overall goals of the workshop were to:

1. Assess the current state of QBO research, including both modelling and observations.
2. Identify the challenges and priorities for:
   a. Understanding and simulating the equatorial QBO (*e.g.* understanding its potential sensitivities to model formulation);
   b. Understanding and reproducing the impacts of the QBO (*e.g.* at high latitudes or at the surface);
   c. Making robust predictions about the QBO and its responses to external forcings such as future climate change.
3. Design coordinated model experiments to address these challenges.
4. Determine what metrics, both simple and process-based, are needed to analyse the results.

In this article we will summarize the science presented and briefly describe the purpose and scope of the planned coordinated model experiments. We will also indicate how this QBO modelling activity is related to other current initiatives such as the SPARC Reanalysis Intercomparison Project (S-RIP), the SPARC activity on Gravity Waves, and others.

The scientific focus of this workshop was on improving the representation of the QBO in GCMs, taking the view that this is a prerequisite to improved representation of QBO influences on other regions of the atmosphere and on the transport of chemical species such as ozone and

Figure 2: Participants of the 1st QBO Modelling and Reanalyses Workshop held from 16-18 March 2015 in Victoria, BC, Canada.

water vapour. Themes of the oral sessions on Monday and Tuesday roughly followed this sequence. Starting from the dependence of GCM QBOs on model resolution, dynamical core formulation and small-scale gravity waves, talks then moved on to interactions between the QBO and the tropical troposphere, followed finally by consideration of QBO extra-tropical influence. All of these themes were then discussed extensively in breakout sessions, culminating in a plan for the design of shared experiments discussed and agreed to in plenary on the final day. A second workshop, intended for 2016 in Oxford, UK, will provide an opportunity to discuss the results of these experiments. This second workshop will also focus more thoroughly on the impacts (*i.e.* teleconnections) of the QBO, building on anticipated progress made in simulating the equatorial QBO itself.

Scientific presentations

After **Lesley Gray** briefly summarized the workshop goals as given above, the workshop began with an illuminating historical review of QBO observations and theory by **Alan Plumb**. Scattered observations starting with tracking of the Krakatau aerosol cloud in 1883 showed that both prevailing easterlies and westerlies were found in the tropical stratosphere, leading to a belief in the presence of permanent westerly and easterly jets. In 1960 the transient QBO was recognized in balloon data by Reed in the US and Veryard and Ebdon in the UK. The phenomenon initially was mysterious both for its quasi-regular period and the apparent downward propagation. Early attempts at explanation, including those involving extraterrestrial influence, were seen to be unsatisfactory. Alan noted that progress began to be made when the focus was placed on understanding the evolution of the angular momentum of the mean equatorial flow. Lindzen and Holton (1968) made the key breakthrough by invoking the mean flow effects of a continuous spectrum of gravity waves forced in the troposphere. Their numerical results showed that the presence of the self-limiting eastward and westward mean flow driving mechanisms could lead to an oscillatory mean wind, with the wind reversals descending with time. Plumb noted that the early papers assumed the stratopause semi-annual oscillation (SAO) was essential for the evolution of the QBO, a notion his own 1977 paper dispelled. The audience discussion focused on the possible role of the SAO in synchronizing with the QBO and on whether the actual mechanism for switching of the sign of the zonal winds in the lower stratosphere, while clear in simplified models, is completely understood in the real atmosphere.

The wave-mean flow mechanism for the QBO is easily implemented in simplified models and the basic dynamical explanation appears robust. Despite this it has proven difficult to realistically simulate the QBO in comprehensive GCMs (Baldwin *et al.,* 2001). A key goal of the workshop was to improve upon this situation by instigating collaboration between QBO researchers at different institutes. Improving the representation of processes driving the QBO has two aspects: understanding how model formulation affects the QBO (*e.g.* vertical resolution, parameterization of non-orographic gravity wave drag), and making meaningful comparisons with observations and observationally constrained models (reanalyses). Regarding the first aspect, **Scott Osprey** gave an introductory overview of the QBOi project, an emerging SPARC activity, focused on intercomparison of QBOs generated by GCMs. For the second aspect, **James Anstey** introduced the QBO activity of the SPARC Reanalysis Intercomparison Project (S-RIP). In practice it is difficult to separate these two aspects, which of course is what motivated the inclusion of them both in the workshop. A number of the workshop participants are involved in both activities.

To characterize the current *status quo* of the QBO in climate models, **Verena Schenzinger** gave an overview of QBOs represented by CMIP5 and CCMVal-2 models. She showed a number of systematic differences between QBOs in these models and the QBO as shown by reanalyses, with free-running models on average showing weak vertical penetration as well as reduced latitudinal width in the lowermost tropical stratosphere, and reduced variability between QBO cycles. Connecting these deficiencies to the nature of the QBO forcing is likely to require insight into the spectrum of waves that force the QBO, and this spectrum spans a vast range of spatial scales. **Stephanie Evan** gave an overview of the SPARC Gravity Wave Activity, which is focused on improving our understanding of small-scale gravity waves in observations and high-resolution models (including regional models, such as WRF). Gravity waves are believed to make an important contribution to forcing the QBO, particularly the easterly phase, and Stephanie showed WRF results with resolved gravity waves corroborating this. Whether GCMs represent gravity wave forcing accurately is a major question; at horizontal resolutions typically used

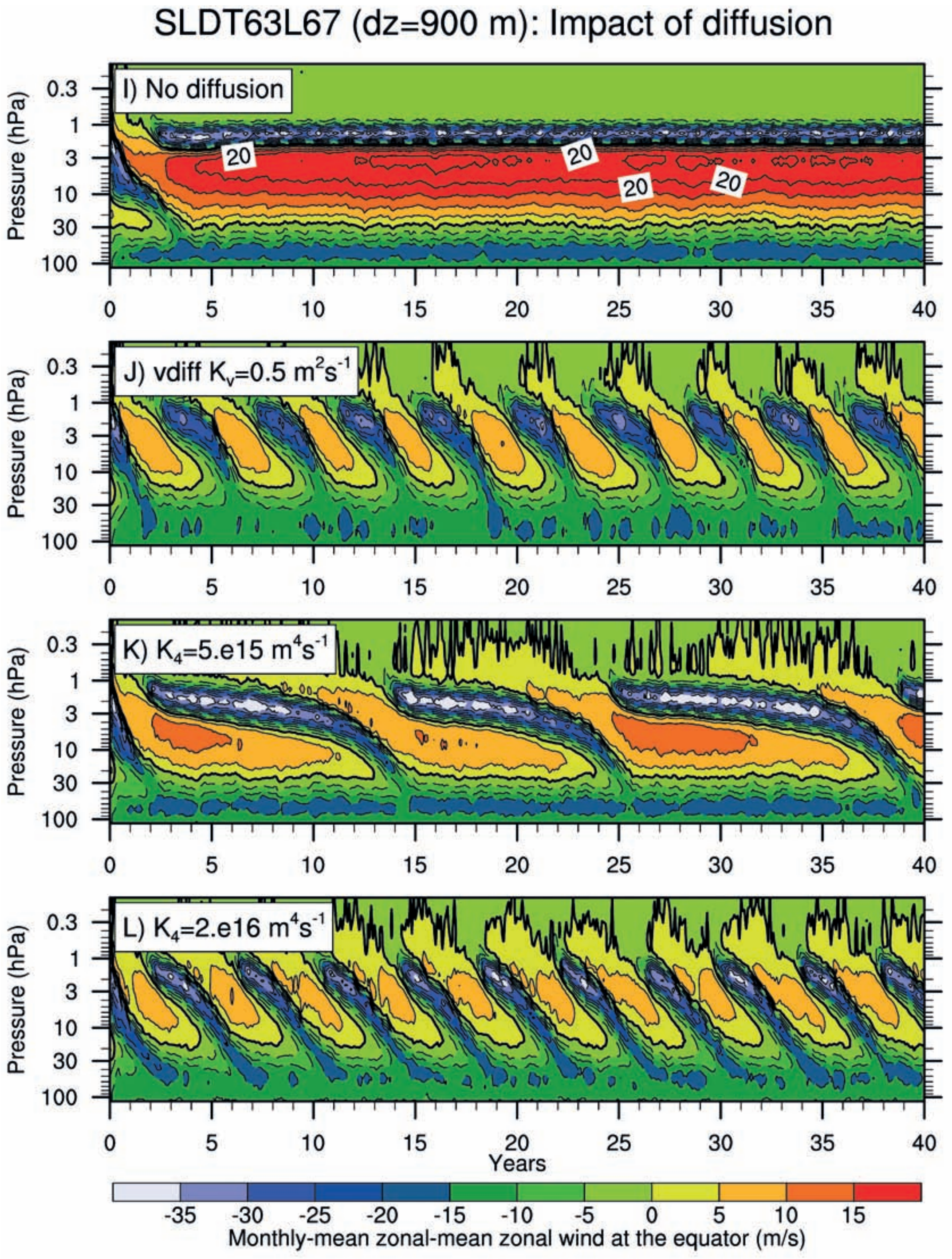

Figure 3: Results from Christiane Jablonowski and Weiye Yao showing the sensitivity of equatorial zonal-mean zonal wind to vertical and horizontal diffusion coefficients in idealized dynamical core experiments using NCAR's Community Atmosphere Model (CAM), Version 5.

in climate models, all aspects of the small-scale waves – their generation in the troposphere, their propagation to stratospheric altitudes, and their dissipation that forces the QBO – must be parameterized. The best approach to parameterization is not yet clear, and different modelling groups have taken varied approaches to the problem. Some of these approaches were indicated during the conclusion of the first session, when representatives of the different modelling groups presented very brief summaries of how their current best model versions represent the QBO, and what model features were implemented to accomplish this (*e.g.* stochastic gravity wave parameterization, *etc.*).

Some more thorough analysis on how model formulation may vary was presented in the afternoon talks. **Jadwiga Richter** and **John Scinocca** both discussed the sensitivity of the QBO to vertical resolution and non-orographic gravity wave drag, while **Christiane Jablonowski** discussed the long period equatorial mean wind oscillations appearing in a set of idealized 'dynamical core' GCM experiments (**Figure 3**). The QBO can be viewed as a coherent large-scale manifestation, or 'self-organization', of small-scale fluctuations that in current climate models must be parameterized to some extent. As such its sensitivity to parameterization choices might be expected, but the large impact of the chosen dynamical core is perhaps more surprising since important parameterizations used in complex GCMs – gravity wave drag, moist convection, realistic radiative transfer – are excluded from these experiments. One way to examine small-scale behaviour more closely is to explicitly represent it using very high-resolution model runs, with correspondingly short integration periods, as presented by **Laura Holt**. But for longer integrations, which are required to represent many QBO cycles, non-orographic gravity waves will need to be parameterized for the foreseeable future. **François Lott** discussed methods for stochastic parameterization of gravity waves that are linked explicitly to wave sources (tropospheric convection and fronts). The fact that models with high horizontal resolution can still require parameterized wave drag, as shown both by Jadwiga and Laura, suggests that careful attention to parameterization details will remain important.

The workshop also benefitted from the presentation of a dozen excellent posters. These included further characterization of QBO sensitivity to model formulation (**Andrew Bushell**, **Neal Butchart**, **Shingo Watanabe**, **Kohei Yoshida**, **James Anstey**, **John Scinocca**), diagnoses of the QBO in ozone (**Peter Braesicke**), analyses of QBO amplitude and equatorial wave forcing in reanalyses (**Yoshio Kawatani**, **Young-Ha Kim**), high-latitude QBO impacts and their mechanisms (**Hua Lu**, **Peter Watson**, **Lesley Gray**, **Verena Schenzinger**), and the partial seasonal synchronization of the QBO (**Kylash Rajendran**). A full description of the presented posters (titles and abstracts) is available at **http://users.ox.ac.uk/~phys0772/srip/Victoria_QBO_posters.html.**

Tuesday morning began with **Tim Dunkerton** discussing the cycle-to-cycle variability of the QBO. Such detailed characterization of the observed QBO helps in understanding what determines the duration of QBO cycles and their partial synchronization with the annual cycle. Variability in the descent rate and duration of QBO cycles might be affected by downward influence from the SAO, fluctuations in the strength of the tropical upwelling of the Brewer-Dobson circulation, and seasonal variations in tropical tropospheric wave sources. **Marv Geller** discussed observations of ENSO-modulated variations in the QBO descent rate (Taguchi, 2010), presumably caused by ENSO modulation of tropical deep convection, as well as observed evidence for QBO influence on deep convection via its modulation of the tropical tropopause height (Collimore *et al*., 2003, Liess and Geller, 2012). This suggests a two-way picture of tropical stratosphere-troposphere coupling, analogous to how stratosphere-troposphere coupling in the extra-tropics is viewed. An idealized modelling framework for such two-way coupling was presented by **Shigeo Yoden**, who used a regional model with resolved moist convection to demonstrate QBO-like oscillations that propagated downward not only in the stratosphere, but also in the troposphere, with associated modulations of precipitation and convective organization. All the foregoing results suggest that the two key challenges from the workshop goals – simulating the equatorial stratospheric QBO, and representing its impacts on other regions – are not strictly separable, due to this two-way coupling. As models improve their QBOs, it should become more feasible and interesting to validate their representation of these coupling mechanisms – *e.g.*, to determine how robust is the effect of QBO-induced modulation of tropical tropopause height on tropical deep convection.

Mark Baldwin described a recent analysis of observations to characterize the coupling of the equatorial QBO with the stratospheric polar vortex. This coupling and further connections to phenomena such as the North Atlantic Oscillation with strong manifestation at the surface have important implications for weather and seasonal forecasting in the extra-tropics (*e.g.* Thompson *et al*., 2002). Exploiting such potential predictability in practical prediction systems depends in part on the accuracy of the forecasts of the QBO itself, an issue discussed by **Kevin Hamilton**. He highlighted recent seasonal forecasting results from Scaife *et al*., (2014) suggesting that the potential predictability of the QBO itself has not yet been fully realized in GCM forecasts; doing so may require correct representation of subtleties associated with inter-cycle variability such as the QBO seasonal synchronization discussed earlier in the session.

Forecasts and hindcasts from realistic initial conditions are a demanding test of how accurately a model represents the processes that drive the QBO, as discussed by **Tim Stockdale** who showed results from ensembles of ECMWF seasonal forecasts (**Figure 4**). This 'seamless' approach to QBO modelling – *i.e.*, using short-timescale forecasts to understand model errors that will ultimately

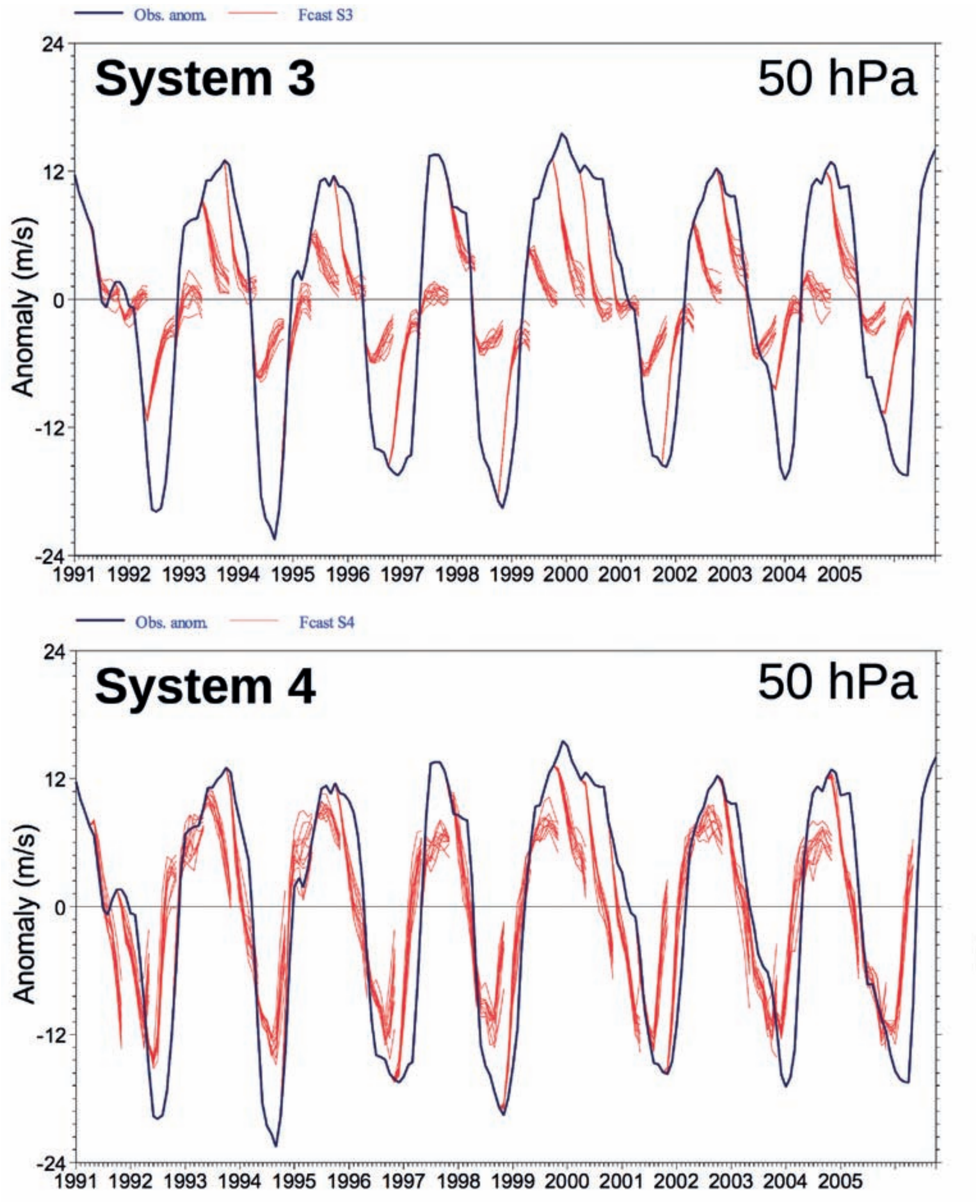

Figure 4: Results from Tim Stockdale showing ensembles of QBO forecasts (50hPa equatorial zonal-mean zonal wind) in two versions of the ECMWF seasonal forecasting system. System 4 has higher model resolution, lid height, and the non-orographic gravity wave drag parameterization is optimized for QBO forecasts and the Southern Hemisphere polar night jet. System 3, in contrast, used no tuning of stratospheric physics.

degrade long-timescale simulations – has been adopted as one of the coordinated model experiments, as described in more detail below. Understanding the origin of model errors in QBO structure, such as the extent of its downward penetration and meridional extent, is important for improved representation of QBO teleconnections. Although it was widely agreed at the workshop that it is very desirable to focus attention on those aspects of QBO structure that strongly affect teleconnections, it is unfortunately still unclear what aspects of the QBO are most relevant for the coupling with higher latitudes. This question has been the subject of numerous modelling studies (see Anstey and Shepherd 2014 for a review) and there are a number of proposed mechanisms (*e.g.* Garfinkel *et al.*, 2012; Watson and Gray, 2014). As far as diagnosing these teleconnections, Mark pointed out the importance of the choice of metrics used to define the extra-tropical state. An assessment of teleconnections using a variety of metrics for extra-tropical variability – *e.g.* the NAO index, blocking frequency, *etc.* – is planned within the S-RIP project, which will help to validate such teleconnections in GCMs.

Coordinated experiments

A key workshop outcome was the proposal of a series of coordinated model experiments for intercomparison. As already noted, the immediate goal is to improve the fidelity of modelled QBOs and thus the circulation in the tropical stratosphere, this being viewed as a prerequisite to addressing the question of QBO teleconnections. The experiment designs resulted from a series of discussions, beginning with the Tuesday afternoon being devoted to breakout groups led by **Matt Hitchman**, **Charles McLandress**, **Mark Baldwin**, **François Lott**,

Alan Plumb, and **Tim Stockdale**. This was followed by synthesis of the breakout groups' ideas into a coherent plan during plenary discussion on the Wednesday morning.

Outlines of the proposed experiments are now online at the QBOi discussion board: **http://qboiexperiments.blogspot.co.uk**. Briefly, the proposed experiments are:

1. Climate runs (interannual to decadal timescales) to examine the robustness of future projections of the QBO. Each modelling group will use its 'best' QBO to run AMIP-type experiments with both present-day and doubled carbon dioxide concentrations.
2. Initialization runs (seasonal timescales) to analyse model uncertainty in processes that force the QBO. For those groups able to perform ensembles of seasonal forecasts, a common set of initial states will be used to examine the short-term evolution of the QBO.
3. Nudged runs, also to examine uncertainties in QBO forcing. By artificially imposing the zonal-mean state, the response of model processes, such as resolved wave forcing, can be clearly diagnosed. Although the artificial nature of this method is a disadvantage, it has been used successfully for this purpose in a number of studies.
4. Dynamical core runs, to better understand uncertainties associated with model formulation. As noted above, it has been shown that dynamical core formulation can strongly influence simulated QBOs. For those groups with access to more than one dynamical core, a set of common experiments using Held-Suarez forcing will be proposed for QBO comparisons.

At present, experiments (1) and (2) are viewed as the priority. Experiment (1) is attractive because it is easily performed by any modelling group, and will immediately give an indication of the robustness of future predictions of the QBO under forced climate change. It has the disadvantage, however, of offering only limited insight into the mechanisms leading to differing QBO predictions. Experiment (2) allows for detailed diagnosis of the process uncertainties that affect the QBO. Using initialized experiments enables model tendencies (*i.e.* the mean-flow forcing that drives the QBO) to be evaluated under conditions of approximately 'fixed' mean-flow conditions, due to the common initialization. While the mean-flow is not actually fixed, the long memory of tropical stratospheric winds implies a time lag on the order of a week or more before substantial mean-flow changes occur. Similar insight might be gained from experiment (3), but the initialization experiments have the advantage of not being artificially constrained by nudging. On the other hand, **Kevin Hamilton** noted that a simplified 'initialization' experiment could be done using a nudging setup and simply turning off the nudging at the desired 'initialization' time.

Some discussion of diagnostics and metrics also occurred, where we agreed that 'metrics' would denote typically single numbers, judiciously chosen, that allow rapid and objective comparison between model simulations. **Neal Butchart** noted that the use of metrics was highly effective in CCMVal, and suggested that the workshop participants propose suitable QBO metrics for use by the wider climate community. A suitable choice of metrics is of course important for optimal comparison of models with observations and reanalyses.

Participants expressed the hope that the scientific outcomes of this rather focused QBO workshop will be connected with the wider climate research community, and links with other established international programs were discussed. **George Boer** gave an overview of the Decadal Climate Prediction Project, concerned with predictability at seasonal to decadal timescales, relevant to the WCRP Grand Challenge on Regional Climate Information (**http://wcrp-climate.org/gc-regionalclimate**). **Shigeo Yoden** described the upcoming 'Years of the Maritime Continent 2017-2019' activity. As noted earlier, science resulting from the QBO workshop is closely related to the SPARC Gravity Wave activity and the S-RIP activity. Issues related to the QBO also fall within the remit of the SPARC DynVar project, and **Shingo Watanabe** commented on this. In particular the DynVar data request for CMIP6, which includes stratospheric dynamical diagnostics previously unavailable from major MIPs, may be relevant for future work analysing QBOs in those models. A broad DynVar goal is to improve the representation of dynamical variability in climate models. Bearing this in mind, **Marv Geller** noted it is important that model changes leading to improved QBO simulation do not do "terrible violence" to the rest of the model; interaction with the aforementioned projects will encourage a more pacifistic approach.

Summary

Realizing all of the predictability

associated with the QBO remains a tantalizing prospect for both forecast and climate models. Uncertainties and model errors of important QBO-driving processes such as small-scale gravity waves have not been resolved, but the Victoria workshop has created a road map for making collaborative progress on these issues, and participation by any interested modelling group is welcome. Analysis of the proposed experiments will be presented at next year's follow-on QBO workshop, at which time we anticipate more emphasis on QBO teleconnections will be possible.

Acknowledgements

We thank the UK Natural Environment Research Council (NERC) for financial support that made the workshop possible. Special thanks also go to John Scinocca (CCCma) for local organizational support and to the workshop rapporteurs whose careful notes informed this report.

Online resources

Experiments discussion page:
http://qboiexperiments.blogspot.co.uk

Workshop agenda (with titles and abstracts of presentations): **http://users.ox.ac.uk/~phys0772/srip/Victoria_QBO_agenda.html**

QBOi website: **http://users.ox.ac.uk/~astr0092/QBOi.html**

S-RIP QBO and tropical variability website: **http://users.ox.ac.uk/~phys0772/srip/**

Glossary of acronyms

AMIP – Atmospheric Model Intercomparison Project
CCMval, CCMval-2 - Chemistry-Climate Model Validation Activity, phase 1/2
CMIP5, CMIP6 – Coupled Model Intercomparison Project, phase 5/6
DynVar – Dynamical Variability
CCCma – Canadian Centre for Climate Modelling and Analysis
ECMWF – European Centre for Medium-range Weather Forecasts
ENSO – El Niño Southern Oscillation
GCM – General Circulation Model
MIPs – Model Intercomparison Projects
QBO – Quasi-Biennial Oscillation
QBOi – QBO intercomparison/Initiative
S-RIP – SPARC Reanalysis Intercomparison Project
SAO – Semi-Annual Oscillation
WRF – Weather Research and Forecasting model

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Bicentenary of the Great Tambora Eruption: Implications for Stratosphere-Troposphere Processes

Stefan Brönnimann[1,2], Martin Grosjean[1,2], Fortunat Joos[1,3], Willy Tinner[1,4], Christian Rohr[1,5], Christoph C. Raible[1,3], Florian Arfeuille[6]

[1]Oeschger Centre for Climate Change Research, University of Bern, Switzerland, **stefan.broennimann@giub.unibe.ch**, [2]Institute of Geography, University of Bern, Switzerland, [3]Physics Institute, University of Bern, Switzerland, [4]Institute of Plant Sciences, University of Bern, Switzerland, [5]Institute of History, University of Bern, Switzerland, [6]Swiss Federal Institute for Materials Testing and Research, Empa, Dübendorf, Switzerland

From 7 to 10 April 2015 an international conference organized by the Oeschger Centre for Climate Change Research and co-funded by SPARC commemorated the 200-year anniversary of the 1815 Tambora eruption. The goal of the conference was to discuss progress in our current understanding of stratosphere-troposphere processes. Around 130 scientists participated in the meeting, including four scientists from Indonesia (**Figure 5**). The conference was interdisciplinary, since the understanding of volcano-induced effects on climate requires a comprehensive 'Earth and human systems' perspective. Consequently, the speakers came from a broad range of different fields encompassing volcanology, atmospheric physics and chemistry, dynamical climatology, paleoclimatology, history, ethnology, and arts.

Three sessions were particularly relevant for the SPARC community (see the Past Global Changes (PAGES) Magazine for a conference summary focusing on palaeoclimatological aspects): the opening session, the session on plumes and volcanic aerosols, and the session on modelling volcanic effects on climate. In this report, we focus on these three sessions and our general understanding of the effect of volcanic aerosols on climate.

From the Earth's Interior to the Stratosphere

In the opening session **Clive Oppenheimer**, **Stephen Self**, and **Adjat Sudradjat** gave an overview of the Tambora eruption processes (Oppenheimer, 2003). During the 1815 eruption about 60Tg of sulfur dioxide (SO_2) were emitted into the stratosphere, where the SO_2 was oxidized to sulfate aerosols (Self *et al.*, 2004; Kandlbauer and Sparks, 2014). In the following session on plumes and volcanic aerosols, **Hans Graf** pointed to difficulties in understanding and modelling the dynamics of volcanic plumes. This is highly relevant as plume dynamics are important for estimating the vertical distribution of SO_2 emissions (Herzog and Graf, 2010). **Alan Robock** summarized what we can learn from volcanic eruptions for assessing geoengineering proposals, including the impacts of stratospheric aerosols on ozone depletion, summer monsoon failures, whiter skies, less solar energy generation, and rapid warming if stratospheric geoengineering were halted. **Susan Solomon** highlighted the role of small eruptions and the importance of considering aerosols in the lowermost stratosphere (see also Ridley *et al.*, 2014). From these presentations, the question emerged whether our current view of volcanic effects on climate is indeed correct or needs to be challenged. Is it really only large, tropical, explosive eruptions that have an effect? That only the SO_2 matters? And that only the large-scale stratospheric meridional circulation controls the aerosol amounts? Transport pathways may be more complex or more direct, smaller eruptions and high latitude eruptions may play a significant role, and even tropospheric eruptions might play a larger role than previously thought (see also Gettleman *et al.*, 2015). Perhaps also ash should be considered in order to comprehensively assess volcanic effects on the climate (**Figure 6**).

Based on the contribution of Hans, the altitude distribution of volcanic emissions is still a major source of uncertainty. One way of determining the vertical distribution of volcanic emissions is inverse modelling of volcanic plumes from satellite imagery. **Petra Seibert** and **Marie Boichu** presented such inverse modelling approaches (Seibert *et al.*, 2011; Boichu *et al.*, 2013). Further presentations in that session addressed the way in which volcanic SO_2 and aerosols can be monitored from space (**Fred Prata**, **Riccardo Biondi**).

While the above-mentioned presentations mostly focused

Figure 5: Participants of the conference "Bicentenary of the Great Tambora Eruption" in Bern, 7-10 April 2015.

on observations, this is hardly possible for eruptions as far back as Tambora, although **Christos Zerefos** demonstrated how paintings of sunsets can be used to estimate aerosol optical depth (Zerefos *et al.*, 2014). **Florian Arfeuille** presented model results suggesting that around two thirds of the stratospheric aerosols were transported to the Southern Hemisphere (Arfeuille *et al.*, 2014), in agreement with new ice core estimates (Sigl *et al.*, 2013). This is interesting in light of the fact that climate proxies from the Southern Hemisphere only show very weak signals of volcanic eruptions, including after Tambora.

Modelling Climate Effects of Volcanic Eruptions

In the session on volcanic eruptions in climate models, **Eduardo Zorita** started with an overview of volcanic effects on the climate system using model simulations of the last millennium. To broaden the view, the shift of the climate from the Medieval Warm Period to the Little Ice Age was also introduced. Modelling volcanic eruptions is not straightforward. Although the decreased short-wave radiation must lead to a cooling, which is more pronounced over land than over oceans, the magnitude and spatial patterns may be difficult to model. Factors such as cloud cover may reinforce or dampen the temperature perturbation induced by volcanic aerosols. The hemispheric or global cooling found in model simulations is often stronger than that found in proxy reconstructions. Still, it remains unclear whether this is due to a model sensitivity that is too large (*e.g.* a misrepresentation or lack of relevant processes in the models) or a proxy sensitivity that is too small (*e.g.* an inadequate selection of potentially less sensitive proxies).

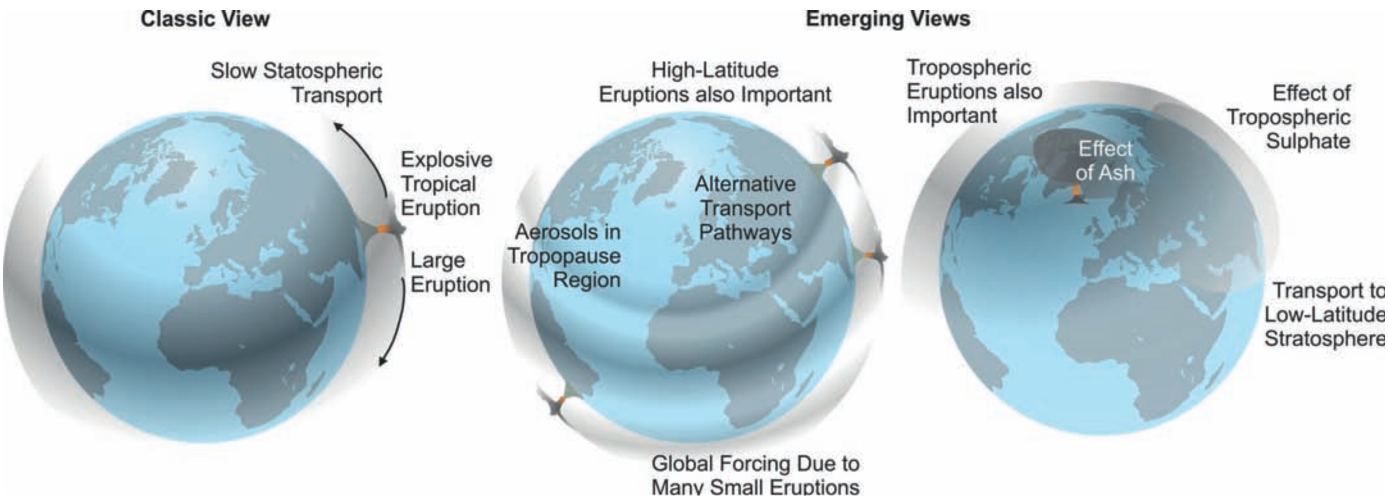

Figure 6: The classic view that only large, tropical volcanic eruptions affect climate perhaps needs to be revised.

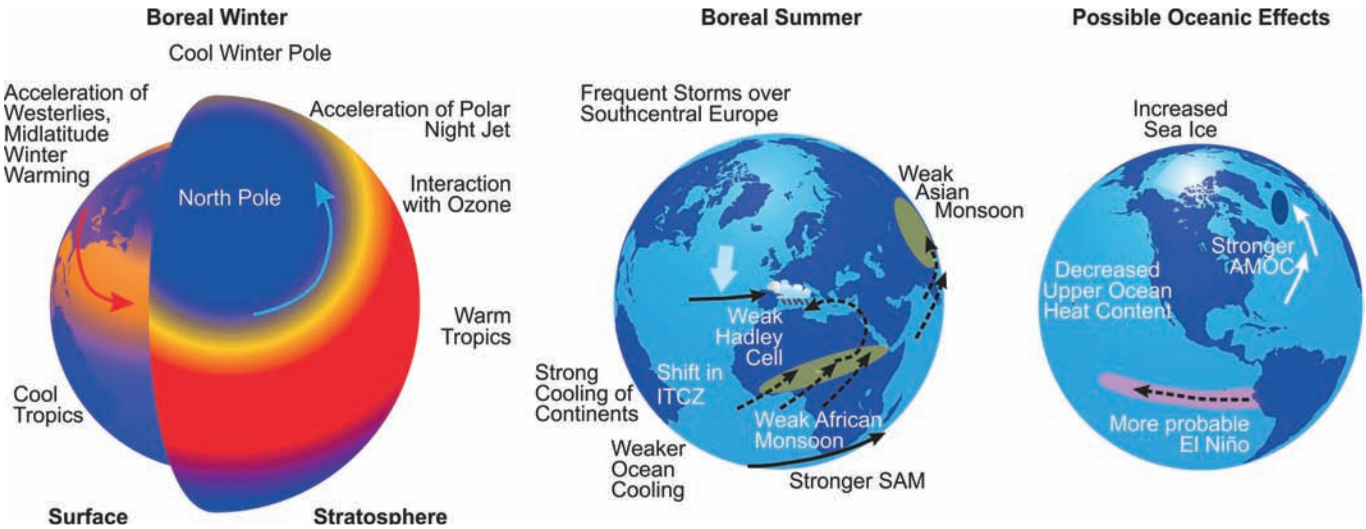

Figure 7: Possible effects of volcanic eruptions on the circulation of the stratosphere and troposphere (left and middle) and on ocean and sea ice (right) discussed at the Bern meeting.

Another focal point was the water cycle response to volcanic eruptions. **Gabi Hegerl** analysed precipitation and temperature in climate model simulations and streamflow in observations. The deceleration of the global water cycle is a direct effect of the decrease in surface net shortwave radiation. Using model simulations of very strong eruptions, **Claudia Timmreck** investigated, amongst other things, volcanic effects on ocean dynamics, the carbon cycle, and marine and terrestrial biogeochemistry. She pointed to the importance of the microphysical treatment of volcanic aerosol size distribution, which is mostly neglected in current modelling exercises (Timmreck, 2011). **Thomas Frölicher** summarized the state of knowledge of the volcanic effect on carbon stocks, highlighting the importance of changes in precipitation, temperature, and diffuse radiation (increasing photosynthesis) for the carbon cycle. The results presented showed that the effect of volcanic eruptions on the carbon cycle is an interesting test of our system understanding and may deliver an additional constraint on Earth system models.

Volcanic eruptions also affect the climate system indirectly through changes in atmospheric circulation. The well-known winter warming that occurs from Central Europe to Russia following tropical volcanic eruptions (**Figure 7**), which is known from direct observations and reconstructions (*e.g.* Fischer *et al.*, 2007), is not well reproduced by climate models. Although the winter warming is primarily induced by changes of the temperature gradient in the stratosphere, the role of the interaction with planetary waves and the role of the background state of the stratosphere need further investigation (Muthers *et al.*, 2014). This indicates that we may not have fully understood all processes. Using model simulations, **Kirstin Krüger** presented evidence that very large explosive volcanic eruptions can lead to a strengthening of the Southern Annular Mode.

The 1815 Tambora eruption was preceded by an unknown eruption that occurred arguably in late 1808 (Guevara-Murua *et al.*, 2014). **Matthew Toohey** presented the effect of such ‘double eruptions’, which have often been followed by decadal-scale climate anomalies. An interesting conclusion was that two closely spaced eruptions of Tambora-magnitude could have a larger cumulative climate impact than a single very large eruption, perhaps triggering abrupt climate change. One reason for this behaviour is the reduced ocean heat uptake (see Figure 6). Although volcanic eruptions cool the land more than the ocean, the effect on the ocean is longer lasting and may trigger interactions with the ocean circulation. Furthermore, sea-ice increases in model simulations after eruptions and may trigger feedback processes with ocean circulation and salinity. It has been suggested that volcanic eruptions are able to excite El Niño events in the tropical Pacific (Adams *et al.*, 2003) or that they favour a positive mode of the Atlantic Meridional Overturning circulation (AMOC, Stenchikov *et al.*, 2009). **Didier Swingedouw** found in model simulations and observational data from the last millennium that volcanic forcing excites bidecadal variability in the North Atlantic, leading to constructive or destructive interferences for recent volcanoes (last 60 years), potentially explaining two Great Salinity Anomalies as well (Swingedouw *et al.*, 2015).

Because of the stronger cooling of landmasses than the ocean surface, summer monsoons generally weaken in model simulations after volcanic eruptions, including Tambora (Kandlbauer *et al.*, 2013), and the ITCZ may shift to the hemisphere that cools less. Using climate model simulations, **Martin Wegmann** (University of Bern, Switzerland) found that the weakening of the African monsoon and thus of the northern Hadley circulation also weakens the Azores high. This may be the cause for the increased rainfall in south-central Europe after volcanic eruptions due to more convection and a southward shift of the Atlantic storm track (Wegmann *et al.*, 2014).

Learning from Tambora

Have we understood volcanic effects on climate sufficiently well? A brief overview of some proposed volcanic effects on the climate system is given in Figure 7. Understanding them requires understanding stratosphere-troposphere coupling, teleconnections in the atmosphere, ocean-atmosphere-sea-ice interactions, and interactions with the global biogeochemical cycle. Not all of these effects are well understood and some are clearly speculative. Studying the Tambora eruption forces us to consider the entire Earth system and all interactions – as well as the human system, which was discussed in several other sessions. Science has already learned a lot from studying the Tambora eruption, and it will learn more in future.

The conference also addressed future undertakings of the scientific community. To study volcanic effects on climate with a consistent modelling protocol, the VolMIP initiative (Model Intercomparison Project on the climatic response to volcanic forcing) was started and advertised at the meeting. VolMIP is endorsed by CMIP6, the latest Climate Modelling Intercomparison Project. The meeting also showed the links between SPARC and the PAGES, which also co-sponsored the meeting. PAGES co-chair **Hubertus Fischer** explored the interest in the community to engage in a PAGES ‘Volcanic Forcing Working Group’. This might open interesting points of contact with SPARC’s SSiRC activity (Stratospheric Sulphate and its Role in Climate), again demonstrating the Earth system perspective entailed by the study of volcanic eruptions and perhaps bringing two international projects a little closer together.

Acknowledgements

The meeting was sponsored by the Oeschger Centre for Climate Change Research of the University of Bern, the Swiss National Science Foundation, PAGES, SPARC, the Swiss Academy of Sciences, and the Johanna Dürmüller-Bol Foundation.

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Advert

SPARC workshop on Stratospheric Temperature Trends

8-9 April 2015, Victoria, BC, Canada

Bill Randel[1], Dian Seidel[2], and Dave Thompson[3]

[1]NCAR, Atmospheric Chemistry Division, Boulder, CO, USA, **randel@ucar.edu**, [2]Air Resources Laboratory, NOAA, Silver Spring, Maryland, USA, [3]Department of Atmospheric Sciences, Colorado State University, Fort Collins, CO, USA.

Understanding past and future stratospheric temperature trends is a key topic for many SPARC-related activities, for the WMO/UNEP Scientific Assessments of Ozone Depletion, and increasingly for the IPCC Assessment Reports. The long-standing SPARC Stratospheric Temperature Trends (STT) activity has focused on improved understanding of past observations, comparisons with model results, and comprehensive theoretical understanding of stratospheric temperature changes. The work of the STT group over recent years has focused on satellite observational data sets, especially measurements from the Stratospheric Sounding Unit (SSU) (Thompson *et al.*, 2012), and improved climate data sets have recently been produced (discussed below).

Since its inception in the mid-1990s, the STT has met roughly every 18 months to survey and discuss the state of the observations and modelling of stratospheric temperature trends. The most recent workshop was held in Victoria, BC, Canada, from 8-9 April, 2015, hosted by Nathan Gillett and the Canadian Center for Climate Modeling and Analysis. This was an open meeting including members of the STT group and also a number of scientists from groups developing stratosphere-resolving chemistry-climate and ocean-atmosphere models (**Figure 8**). The meeting focused on data development and evaluation efforts, and model comparisons (described in-turn below). A substantial portion of the meeting was devoted to open discussion of future goals and plans for this SPARC activity.

Updates of observational data sets

A key data set for evaluating temperature variability and trends in the middle and upper stratosphere is the climate record derived from SSU (based on merging measurements from 7 different operational satellite instruments from 1979-2006). Comparison of initial versions of SSU climate records constructed by the UK Met Office (UKMO) and NOAA groups showed substantial differences for long-term changes (Thompson *et al.*, 2012). More recently, revised data sets (so-called Version 2, V2) have been derived from both UKMO (Nash and Saunders, 2015) and NOAA groups (Zou *et al.*, 2014). **Cheng-Zhi Zou** described the new V2 NOAA SSU climate record, based on recalibrated and merged SSU measurements (**Figure 9**). Comparisons of global trends with CMIP5 model results showed overall good agreement, which is an improvement of the situation described in Thompson *et al.* (2012). Similar comparison results were presented regarding CCMval chemistry-climate models by **Nathan Gillett**. **Dian Seidel** compared climate records based on the NOAA V2 and UKMO V2 SSU data (the latter available only as global mean values), in addition to comparing three different climate records from the lower stratosphere Microwave Sounding

Figure 8: Participants of the Stratospheric Temperature Trends Workshop held in Victoria, BC, Canada, from 8-9 April 2015.

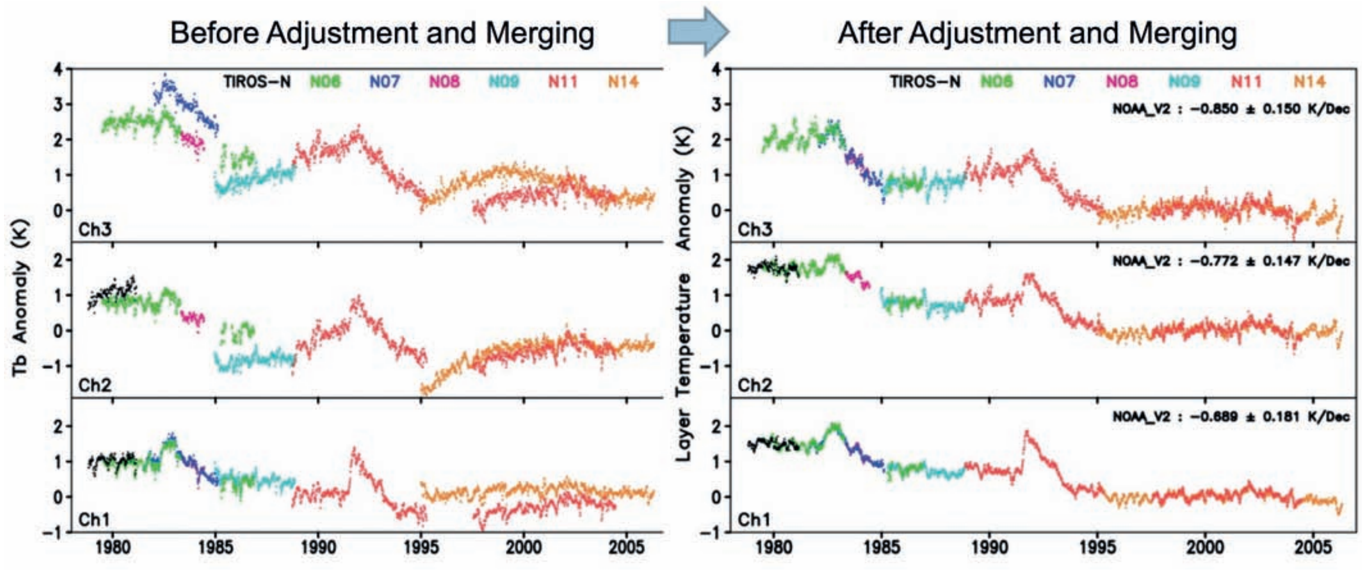

Figure 9: Time series of SSU global mean brightness temperature anomalies before (left) and after (right) merging to produce a stratospheric temperature climate record. Courtesy Cheng-Zhi Zou, NOAA.

Unit (MSU). Results identified differences among the data sets, and examined stratospheric climate signals associated with trends, solar cycle, volcanoes, ENSO, and QBO variations. **Bill Randel** described long-term changes from a new data record combining SSU data with more recent satellite measurements from Microwave Limb Sounder (MLS) and Sounding of the Atmosphere using Broadband Emissions Radiometry (SABER), providing a continuous data set over 1979-2015. **Carl Mears** showed results focused on improving understanding of diurnal sampling corrections to Advanced Microwave Sounding Unit (AMSU) satellite data, which are needed to create merged AMSU data sets in light of drifting satellite orbits.

Other observational data sets were also discussed. **Andrea Steiner** described the advantages of Global Positioning System (GPS) radio occultation data (including long-term stability, all-weather operation, and high vertical resolution), with global records beginning in 2001. Results identified various climate modes that are evident in the data since 2001. **Ben Ho** continued discussions of GPS data, highlighting that the measurements are accurate enough to identify (and potentially correct) radiosonde temperature biases from different sensor types (and also for diurnal variations). He also highlighted the anticipated launches of the COSMIC-2 GPS constellation (in 2016 and 2018), which are expected to lead to over 10,000 GPS occultations per day covering the globe.

Philippe Keckhut showed results from long records of ground-based lidar measurements, including detailed comparisons with AMSU and SSU satellite data. Substantial differences occur due to very different sampling, but the overall trends agree (within uncertainties) between lidars and satellites. **Michael Schwartz** described the new MUSTARD project, aimed at developing long-term upper stratosphere and mesosphere temperature records from limb-sounding radiometers and occultation instruments. Key data sets include UARS MLS, UARS HALOE, Aura MLS, and TIMED SABER. The project aims to provide a bias-corrected long-term record covering ~1991 to present, expected to be available in the next five years.

Model comparisons

Several talks focused on updated understanding of temperature changes in global models, covering both past and future trends. **Rolando Garcia** explored changing temperature trends in the upper stratosphere and mesosphere as a response to greenhouse gas (GHG) and ozone changes using the WACCM model. The combination of these factors leads to substantially different trends (**Figure 10**) for the periods of ozone depletion (~ pre-2000) and ozone increase (after ~2000, as a response to future decreases in stratospheric halogen loading). **Ulrike Langematz** described past and future temperature trends (and their attribution) in the EMAC chemistry-climate model. **Valentina Aquila** showed simulations from

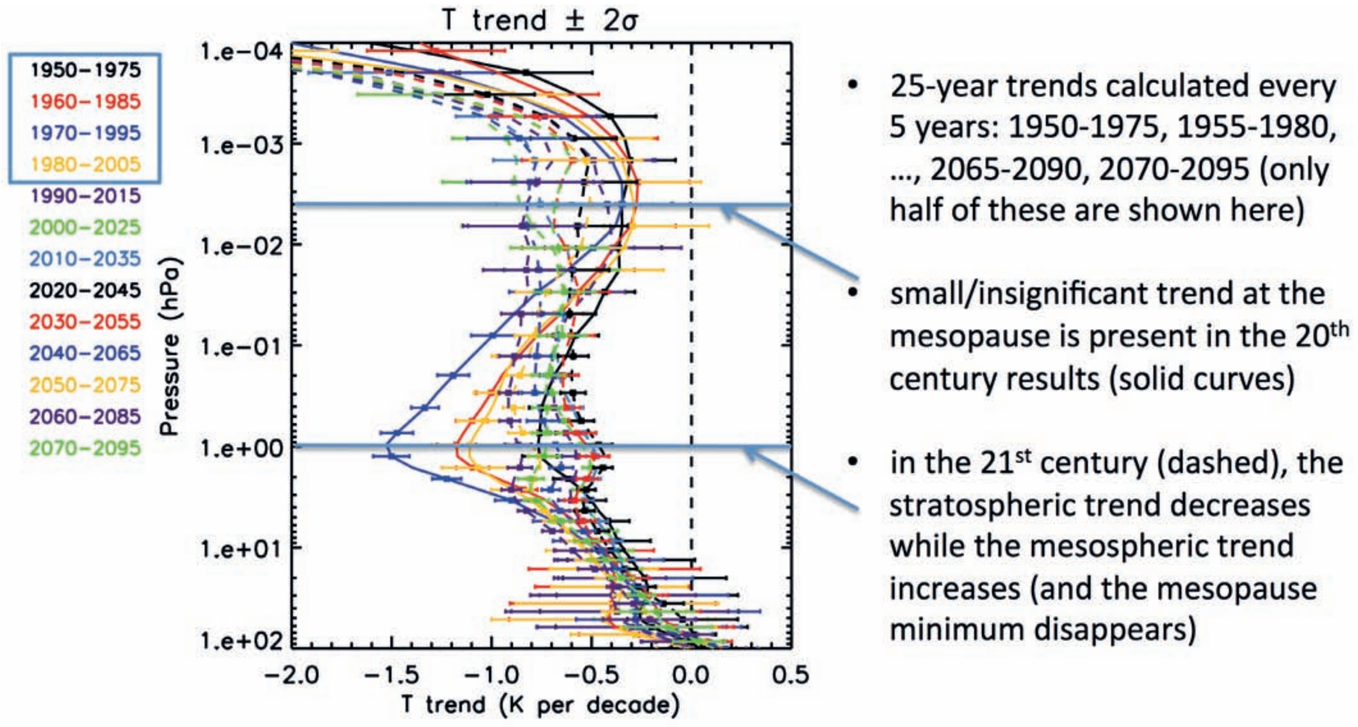

Figure 10: Evolution of global average temperature trends in the WACCM chemistry-climate model during 1950-2095. Results show temperature trends calculated from overlapping 25-year segments. Strong variations in trends in the upper stratosphere are linked to the influence of halogen-induced ozone changes. Courtesy Rolando Garcia, NCAR.

the NASA GEOSCCM model, demonstrating methods to separate anthropogenic *vs.* natural forcings (**Figure 11**). One common theme in these presentations was the distinctive influences of GHG vs. ozone changes in the middle and upper stratosphere of the models; another was that current models tend to overestimate lower stratospheric cooling in the southern hemisphere high latitudes compared to observations.

Other presentations highlighted work aimed at improved understanding of atmospheric variability and interpreting observations and models. **Ben Santer** explored the thermal impact of late 20th and early 21st century volcanic activity, demonstrating statistical techniques to identify and quantify recent volcanic signals. He highlighted a need to reduce uncertainties in estimates of volcanic forcing proxies used in statistical models. **Dave Thompson** described studies that quantify the role of natural variability in climate change, in particular estimating uncertainties in future trends using statistics from observational data. **Qiang Fu** explored the impact of circulation changes on stratospheric temperatures, based on separating dynamically- and radiatively-forced changes. Derived changes in dynamical cooling suggests a strengthening of the stratospheric Brewer-Dobson circulation over the last three decades. **Amanda Maycock** described the contribution of ozone variability to solar cycle changes in stratospheric temperatures. The upper stratospheric solar signal varies by a factor of three among CMIP5 models, and part of this difference is likely due to different ozone specifications (in the models which do not calculate ozone interactively). There are also large differences in the temperature solar cycle derived from current reanalyses. **Shigeo Yoden** showed analyses of Arctic temperatures from paleoclimates, as well as from present and future experiments in CMIP5 model simulations. Empirical Orthogonal Function analyses of temperature fields were used to identify a Polar Jet Oscillation, and warm vs. cold events were studied using cluster analyses. Extreme events occur more frequently in CMIP5 models with a well-resolved stratosphere (so-called high-top models).

Future of the SPARC STT group

During the course of the two-day meeting there were extensive discussions on the future of the STT group, including its potential contributions to SPARC's new implementation plan and the evolution of WCRP. There was strong sentiment for the value of past activities of the STT group, along with a clear mandate from the attendees to continue the STT as a distinct group within SPARC. Possibilities for future focus activities included continued

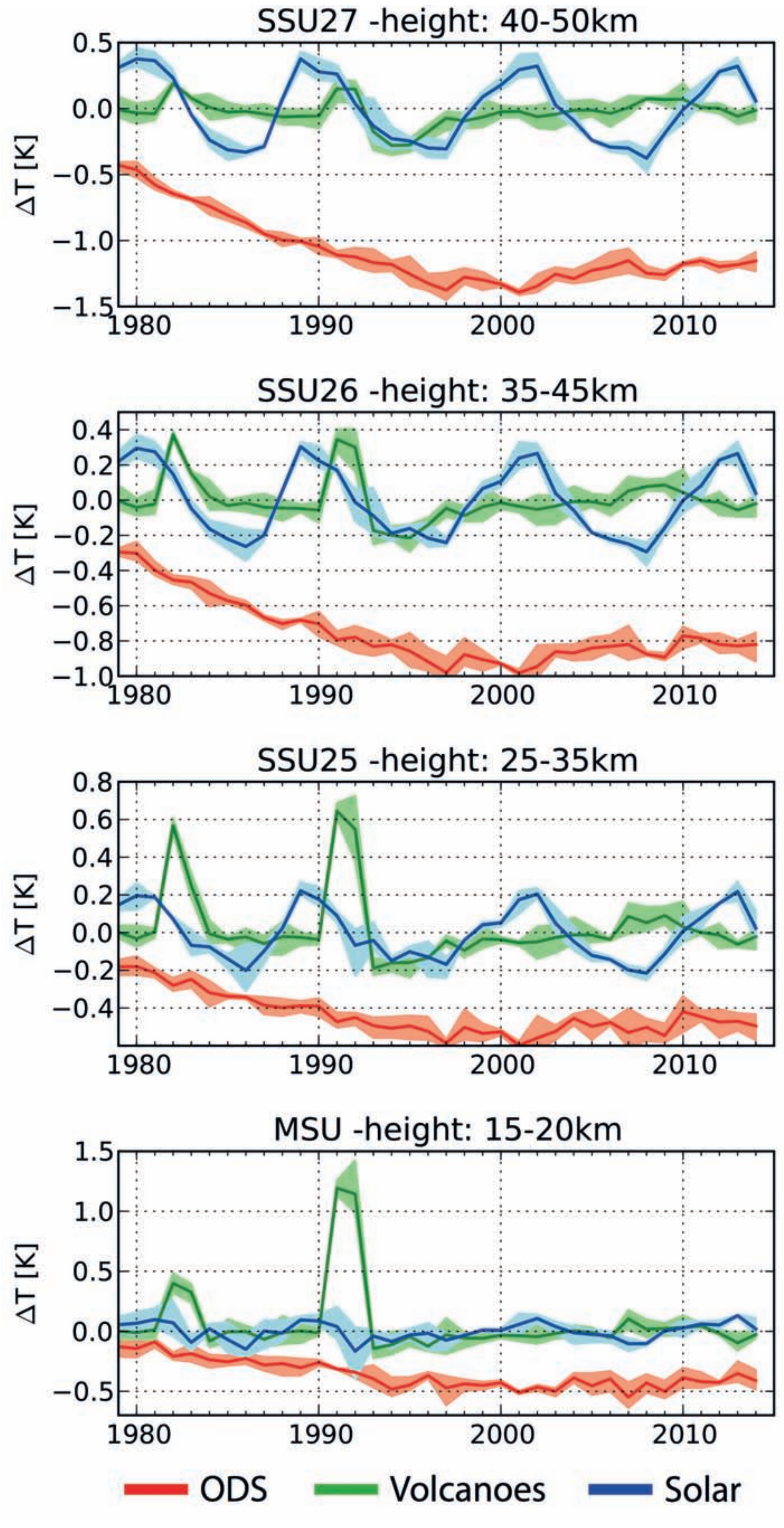

Figure 11: Isolation of global average temperature changes for separate forcings derived from the NASA GEOSCCM chemistry-climate model. Each panel represents temperatures averaged over vertical layers corresponding to the MSU4 and SSU satellite measurements. Courtesy Valentina Aquila, Johns Hopkins/NASA.

work on observational and model data sets, improving specifications for forcing data sets, and a possible extension of the domains of interest in the group upward (into the mesosphere) and downward (into the troposphere).

The current co-chairs (Bill Randel, Dian Seidel, and Dave Thompson) noted that the group had been under roughly the same leadership for more than five years. They expressed their appreciation for the work of the group over the last several years, and for the collegial atmosphere that has become a hallmark of the group since its inception. They also expressed their desire to step aside to allow new leadership to guide the group forward over the next few years.

The group is pleased to announce that **Andrea Steiner** (University of Graz, Austria) and **Amanda Maycock** (University of Cambridge, UK) will assume leadership of the group going forward.

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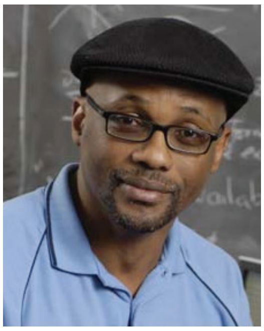
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SPARC Workshop on Storm Tracks, Grindelwald, Switzerland

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Workshop on Solving the Mystery of Carbon Tetrachloride, Zurich, Switzerland

7-9 October 2015
IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2015 Workshop, Rome, Italy

12-16 October 2015
S-RIP 2015 Workshop and SPARC Data Assimilation Workshop, Paris, France

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

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15-17 September 2015
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4-9 October 2015
Training school on Convective and Volcanic Clouds Detection, Monitoring, and Modelling, Castiglione del Lago, Italy

12-16 October 2015
Atmospheric Chemistry and Dynamics Summer School, Jülich, Germany

13-16 October 2015
International Conference on Water Resources Assessment and Seasonal Prediction, Koblenz, Germany

20-23 October 2015
WCRP FP7 EMBRACE Workshop on CMIP5 Model Analysis and Scientific Plans for CMIP6, Dubrovnik, Croatia

9-13 November 2015
2nd Symposium of the Committee on Space Research, Foz da Iguacu, Parana, Brazil

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Publication details

Editing
Fiona Tummon

Design/layout
Carolin Arndt, Petra Bratfisch

Print & distribution
ETH Zurich

ISSN 1245-4680

SPARC Office

Director
Fiona Tummon
Project Scientists
Johannes Staehelin
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Contact
SPARC Office
c/o ETH Zurich
Institute for Atmospheric and Climate Science (IAC)
Universitaetsstrasse 16
CH-8092 Zurich
Switzerland
office@sparc-climate.org