SPARC

2011
Newsletter n°37
July

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE
A Project of the World Climate Research Programme

WCRP World Climate Research Programme

Report on the 18th Session of the SPARC Scientific Steering Group

2-5 February 2011, Pune, India

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The 18th Session of the SPARC SSG was held at the Indian Institute of Tropical Meteorology (IITM) in Pune, India, and was hosted by SSG member Dr. P. C. S. Devara as well as IITM Director and WCRP Joint Scientific Committee (JSC) member Prof. B. Goswami.

Opening session

T. Shepherd and **T. Peter** (SSG co-chairs) opened the meeting by welcoming all participants, particularly the new members of the SSG and the incoming Director of the SPARC Office, J. Stähelin, and warmly thanking the local organisers of the meeting.

A. Busalacchi (WCRP JSC chair) described the planned changes within the WCRP (to be implemented by 2013), which include the strategic evolution of the Core Projects and the establishment of two coordinating councils (one on modelling, the other on climate observations and analysis). Structural changes within the WCRP have been discussed over the last several years (see *e.g.*, Report on the 30th Session of the JSC in SPARC Newsletter No. 33). As part of the overall restructuring, the mandate of SPARC will be expanded to provide a greater emphasis on the couplings and processes of the stratosphere/troposphere system, which implies that tropospheric processes should be addressed in a more explicit way (see further discussion below). Outstanding challenges for the WCRP include how to organise activities on regional climate prediction, how to structure cross-cutting activities, and how to optimally connect the various WCRP activities to the users' needs (see Report on the 32nd Session of the JSC in this issue of the SPARC Newsletter).

A major activity of the WCRP in 2011 is the Open Science Conference (OSC), which will take place from 24-28 October 2011 in Denver, USA. **V. Ryabinin** (WCRP Joint Planning Staff) described the plans for the OSC, including the substantial financial support for early-career scientists and scientists from developing countries, and T. Shepherd (member of the OSC Programme Committee) documented the extensive representation of SPARC within the plenary speakers and session conveners. All SPARC activities were encouraged to make a strong showing at the OSC, *e.g.*, through poster clusters, to develop the connections with tropospheric activities that will be needed for the future evolution of SPARC, and to ensure that SPARC science is well integrated into the WCRP cross-cutting activities.

P. C. S. Devara presented an overview of the regional workshop held at IITM immediately preceding the SSG meeting (see the full workshop report in this issue of the newsletter), which was followed by a discussion of the implications for SPARC. There was a consensus that

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SPARC needed to more actively embrace monsoon research, and that a first step in this direction could involve two specific research activities in collaboration with the Indian community: one focused on the role of the stratosphere in the predictability of monsoon onset, and another focused on the role of the monsoon in determining chemical distributions within the Tropical Tropopause Layer, possibly including a field experiment.

Chemistry-Climate Interactions

P. Newman, **A. R. Ravishankara** and **G. Bodeker** presented different aspects of the recently published "Scientific Assessment of Ozone Depletion: 2010" of WMO/UNEP (the WMO/UNEP Ozone Assessment). Many scientists engaged in SPARC contribute in various ways to the Ozone Assessments, which are produced every four years for the parties that signed the Montreal Protocol. The speakers identified expected needs for the anticipated 2014 assessment to which SPARC could respond through its various activities. These include: updating model simulations; weighting multi-model projections; inferring tropospheric impacts of stratospheric changes; constraining the impact of geoengineering on stratospheric ozone; understanding lower stratospheric ozone trends; inferring changes in the Brewer-Dobson circulation from trace gas measurements; comparing observed and modelled changes in tropospheric ozone; and further constraining the impact of very short-lived halogen species. P. Newman made the case that a better quantitative understanding was needed of the lifetimes of important halogen source gases (*e.g.*, CFC-11, CCl_4), since evidence has emerged that in many cases the actual lifetimes may be considerably longer than those currently assumed in the Ozone Assessment, and in the scenarios used to drive the CCMs. This represents a major uncertainty in reconciling top-down and bottom-up emissions estimates, and in model projections. It was decided to initiate a new SPARC activity to respond to this need. The comprehensive review will include an overview of the theory of estimating lifetimes using models and observations; an update of the kinetic data that determine lifetimes; lifetimes deduced from observed trace-gas distributions; and model estimates of lifetimes, which will require new CCM runs. Groups that contribute to CCMVal will therefore be critical participants in the initiative. The results are expected to be an important input to the next WMO/UNEP Ozone Assessment.

V. Eyring reported on the SPARC Chemistry-Climate Model Validation (CCMVal) activity. Over the last decade, there has been a significant growth in the number and maturity of three-dimensional stratospheric CCMs, such that they now represent a mainstream input into the Ozone Assessment. The evaluation of the strengths and weaknesses of the suite of models is a challenging task. CCMVal has pursued a two-pronged approach. On the one hand, it has coordinated the definition of simulation protocols to ensure that multi-model analyses are comparing 'apples with apples', and it has developed robust multi-model statistical analysis methods. These efforts in themselves have reduced the uncertainty in quantifying the model projections. In parallel with these efforts, CCMVal has introduced a novel approach to compare the results of the individual models in a systematic way by developing performance metrics to separate and grade model performance with respect to key physical processes, as compared with observations. The results of this effort were published last year as a peer-reviewed SPARC report (see the publications section on the SPARC web page, also SPARC Newsletter No. 35), as well as in about a dozen associated refereed journal publications. While the individual models show different strengths and weaknesses, they also show common features, such as the enhancement of the Brewer-Dobson circulation from climate change that will lead to larger column ozone amounts in the extratropics (super recovery) and reduced amounts over the tropics (compared to 1960). As a result, the models consistently predict an increase in ozone flux from the stratosphere into the troposphere over the 21st century. The models also indicate that the stratospheric ozone layer started to experience ODS-induced ozone depletion well before 1980, which is used as the reference for ozone depletion in the WMO/UNEP Ozone Assessments.

Future CCMVal activities will not only aim to continue to improve stratospheric model validation, but also plan to extend the validation of CCM simulations to tropospheric chemistry; note that no similar effort for validation of tropospheric chemistry models has been made in the past, although such model validation is an important task. The planning of the next phase, CCMVal-3, should therefore include discussions and coordination with the tropospheric CCM community. For this purpose the next CCMVal workshop, planned for spring 2012, will explicitly address this issue and invite tropospheric modellers.

With regard to the IPCC AR5, an AC&C/SPARC ozone database[1] was created in collaboration with the SPARC/IGAC cross-cutting activity Atmospheric Chemistry & Climate (AC&C) in response to a request from the CMIP5 activity of the WGCM (CMIP: Coupled Model Intercomparison Project, see further discussion below). This database includes a merged tropospheric and stratospheric ozone time series from 1850-2100 for use in CMIP5 simulations.

M. Chipperfield discussed the status of the cross-cutting activity AC&C, a joint effort of IGBP (the International Geosphere-Biosphere Programme) and WCRP, carried out by their core projects IGAC (International Global Atmospheric Chemistry) and SPARC, respectively. AC&C has defined three modelling activities: (1) Hindcasts 1980-2007: To evaluate tropospheric CTMs and CCMs with respect to past trends and variability. (2) Vertical Distributions: To investigate upper tropospheric chemistry, convection, scavenging, and strat-trop exchange. (3) Atmospheric Chemistry & Climate Model Intercomparison Project (ACC-MIP): To perform time slice runs and emission sensitivity studies complementing CMIP5 (formerly Activity 4).

The ACC-MIP Activity (3) is making progress, with tropospheric chemistry runs in support of AR5 being performed. Two early runs contributed to the combined troposphere-stratosphere ozone database provided to CMIP5 as ozone forcing for models without interactive ozone. Progress in Activities (1) and (2) has been slower than hoped for, partly owing to the involvement of many AC&C scientists in the recent WMO/UNEP "Integrated Assessment of Black Carbon and Tropospheric Ozone"[2]

[1] http://cmip-pcmdi.llnl.gov/cmip5/forcing.html?submenuheader=2#ozone_forcing
[2] http://news.sciencemag.org/sciencenow/Integrated%20Assessment%20of%20Black%20Carbon%20low%20res.pdf

and in the UNECE HTAP report on "Hemispheric Transport of Air Pollution 2010"[3], but partly also because plans for model runs appear to have not been sufficiently coordinated.

The present development of AC&C needs to be seen in the context of the extended mandate given by the WCRP to the new project that emerges from SPARC, calling for an intensification of AC&C-like activities in SPARC, and close collaboration with IGBP/IGAC will become even more important. The extensive discussion of AC&C at the 18th session of the SPARC SSG concluded that:

- the situation with little apparent progress of some AC&C Activities needs to be remedied;
- CCMVal groups should be encouraged to participate in the Hindcast and ACC-MIP Activities, to the extent they are able;
- the next CCMVal workshop should be with the full participation of tropospheric AC&C scientists on the organising committee and a broad invitation to all AC&C modellers;
- there should be a broad-based community discussion of where the AC&C community wants to go in the future, and to consider wider scientific opportunities and imperatives, in particular extending the CCMVal models into the troposphere.

The co-chairs of IGAC and SPARC will develop an action plan to accelerate progress in AC&C.

Detection/Attribution/Prediction

J. Stähelin reported on a new joint activity on "Past Changes in the Vertical Distribution of Ozone" of SPARC, IGACO-O_3/GAW and IO_3C (International Ozone Commission), aimed at updating observed trends in the vertical distribution of stratospheric ozone. Important satellite instruments stopped operation in 2005 (SAGE II, HALOE). While other satellite instruments exist to continue the stratospheric ozone record, their products have not yet been assessed in such a way as to enable trend assessments in the vertical distribution of ozone. As a result, it was not possible to comprehensively assess ozone profile changes after the 2006 WMO/UNEP Ozone Assessment. This new activity intends to construct merged satellite data sets as well as homogenized long-term ground-based measurements to get an update of global stratospheric ozone trends (see report in this issue of the newsletter). This is also of scientific interest because model predictions suggest that climate change and ozone depleting substances will modify ozone profiles in different ways (see CCMVal discussion above). This new activity started with a workshop in Geneva in January 2011 and is planned to complete in time for the results to be used by the 2014 Ozone Assessment.

C. Schiller presented an update on SPARC WAVAS-2 (Water Vapour Assessment-2). The main aim of the assessment is to assess past trends in stratospheric water vapour, and to understand what controls both the magnitude of water vapour entering the stratosphere and the drivers of temporal changes. The report is currently planned to include: (i) data quality problems including sensor characterization by measurements in the AIDA cloud chamber during AquaVit2007 and recent instrumental comparisons from aircraft measurements, (ii) problems concerning supersaturation, taking into account the improved characterization of the instruments, (iii) an upper tropospheric and stratospheric water vapour climatology, including long-term changes, and (iv) a synthesis. Unfortunately the activity is not advancing as quickly as planned.

Stratosphere-Troposphere Dynamical Coupling

A. Scaife summarised the work of WGSIP (Working Group on Seasonal to Interannual Prediction), focusing on results relevant to SPARC. The representation of the stratosphere has been identified as one of the most important opportunities for improvement of seasonal forecast skill in current seasonal prediction systems. In WGSIP's Stratospheric Historical Forecast Project (SHFP) it has been shown that the effects of ENSO on European weather forecasts depend on the representation of the stratosphere in the models. Further analysis of the SHFP archive will be carried forward by the SPARC DynVar activity (see below). It was noted that solar variability could play a more important role than previously believed in driving NAO variability. The CMIP5 decadal predictions could provide another opportunity to assess the role of the stratosphere in driving tropospheric variability, but it is not yet clear how many of the models contributing to this activity will have a well-resolved stratosphere.

E. Manzini reported on the SPARC DynVar activity, which has recently been rejuvenated through a workshop held in Boulder in November 2010. The workshop attracted enthusiastic participation, including a large number of early-career scientists. At the workshop it was decided that DynVar should take a more focused approach, oriented around understanding the two-way dynamical connections between the stratosphere and the troposphere, and take advantage of the archives of model simulations provided by the SHFP and the high-top models contributing to CMIP5. In particular, DynVar will coordinate several CMIP5 synthesis papers. For a full understanding of stratosphere-troposphere connections it is important that the DynVar community actively engage with the coupled atmosphere-ocean modelling community. Therefore, the DynVar community has decided to actively participate in the CMIP5 Analysis Workshop to be held in March 2012, rather than holding a separate DynVar workshop in 2012.

J. Alexander reported on the SPARC Gravity-Wave Working Group, which was rejuvenated several years ago under a more focused mandate to better quantify gravity wave momentum fluxes in observations and models. The goal is to develop methods to merge observational data sets into a coherent set of constraints for improvement of model parameterizations of gravity-wave drag. Recently the working group has published a review paper (Alexander *et al.*, QJRMS, 2010), initiated an ISSI (International Space Science Institute) International Team activity to develop methodologies to merge different observational data sets, and held a Chapman Conference on gravity waves in Spring 2011 (see report in this issue of the newsletter).

K. Matthes reported on SOLARIS, the working group on effects of solar influence on climate. Solar influence on climate is a vast and complex research topic, which has obtained much visibility in climate research. SOLARIS focuses on the solar influence on chemical and dynamical processes

[3] http://www.htap.org/activities/2010_Final_Report/EBMeeting2010.pdf

in the middle atmosphere, including their coupling with the Earth's surface, by using CCMs, mechanistic models and observations. The activity is closely coordinated with the CCMVal and DynVar activities. SOLARIS also provides recommendations on solar irradiance data sets for CCMVal and CMIP5. A recent focus involves examining the possible effect of aliasing between the solar signal and other sources of variability (*e.g.*, SSTs) on the variability of the tropical lower stratosphere, where the significance of the solar signal has been controversial (see the report in SPARC Newsletter No. 36). The SSG approved the recommendation of SOLARIS to strongly coordinate with the HEPPA activity (High Energy Particle Precipitation in the Atmosphere; see also the report in SPARC Newsletter No. 36), which currently lacks a formal home.

Cross-Cutting issues

M. Hegglin reported on results from the SPARC Data Initiative, which aims to intercompare vertically-resolved chemical trace constituent measurements derived from satellite instruments (extending from the upper troposphere to the mesosphere, but with a primary focus on the stratosphere). Accurate knowledge of trace species concentrations (including their variability) is crucial not only for their intrinsic value but also for validation of numerical simulations; the SPARC CCMVal Report noted that for some species the satellite products appear to contradict each other, and recommended an assessment of the various data products currently available to support future model evaluations. The species analysed in the data initiative will include a variety of trace gases not covered in other SPARC activities (CH_4, N_2O, HNO_3, NO_x, HCl, ClO, OClO, HOCl, HF, BrO, SF_6, CO and others), while the analysis of ozone, aerosol and water vapour climatologies will support other ongoing SPARC activities focused on characterizing long-term changes. This work will also complement "data merging" activities currently being carried out by NASA and ESA. The outcome of the SPARC Data Initiative will be a peer-reviewed SPARC Report in the spirit of that produced 10 years ago on middle atmosphere dynamical climatologies. The activity is also being facilitated through an ISSI International Team activity, and all major instrument teams are well engaged.

S. Polavarapu presented the progress of the SPARC Data Assimilation Working Group, which was created in 2002 to coordinate and promote data assimilation relevant to SPARC. Data assimilation is a versatile tool commonly applied to several domains in modern atmospheric sciences. The Data Assimilation Working Group has operated through annual workshops, whose foci vary in order to develop connections with different scientific communities. The last SPARC Data Assimilation workshop, held in June 2010, covered seamless prediction, model error, stratosphere-troposphere coupling, and the role of data assimilation in air quality and climate (see the Report in SPARC Newsletter No. 36). It is unclear exactly how the SPARC Data Assimilation Working Group should evolve within the expanded scope of SPARC, but there seems to be no doubt that the issues addressed by the Working Group are central to progress in many areas of climate research. David Jackson of the UK Met Office will be joining Saroja Polavarapu as a co-leader of the SPARC Data Assimilation Working Group.

T. Shepherd reported on the WCRP Workshop on Polar Predictability (see the Report in SPARC Newsletter No. 36), which was held in Bergen in October 2010. Much of our knowledge concerning physical processes in the polar regions is well established, however the understanding of many of the feedbacks between the different components of the polar climate system and the causality of important modes of variability need further research. The nature of the feedbacks appears to be somewhat different in the two hemispheres, which is reflected in the different scientific questions being asked: for the Arctic the most burning issue is arguably the rate of warming and sea-ice loss, while for the Antarctic it is the response of the ocean, carbon uptake and the West Antarctic ice shelf to circulation changes. The workshop demonstrated the need for a cross-cutting WCRP initiative to address these topics. SPARC will be involved, but to be effective the activity would need to engage virtually every component of the WCRP.

Coordination with other programmes

C. Jakob reported on activities within WGNE (Working Group on Numerical Experimentation). He noted that WGNE plays a unique role within the WCRP by providing a direct link to the operational weather prediction centres. A stronger link to the WCRP core projects is being developed by adding *ex officio* members from the core projects: SPARC is now represented on WGNE by S. Polavarapu. This provides new scientific opportunities for SPARC that could be pursued through joint projects, workshops, *etc*. For example, the SPARC Gravity Wave Working Group could look at high-resolution AMIP (Atmospheric Model Intercomparison Project) simulations. DynVar could become involved in developing diagnostic subprojects focused on the role of the stratosphere for the Transpose-AMIP activity (which seeks to identify climate model errors through short-term forecasts), or could examine verification of stratospheric forecasts. It was suggested that the SPARC Data Assimilation Working Group work together with WGNE to consider defining coordinated experiments concerning the role of the stratosphere in climate and weather forecast models. WGNE will be leading a workshop on physics in climate models in Spring 2012, and Norm McFarlane was nominated to represent SPARC on the Scientific Organising Committee of this workshop.

C. Jakob also reported on developments concerning the GCSS (Global Cloud System Study) within GEWEX. There was a proposal that within the restructured GEWEX, GCSS would evolve into a new project with its own Steering Group. SPARC welcomed this development as it would provide a mechanism to revive the Tropical Tropopause Layer initiative, by providing a clear entry point for SPARC into GEWEX expertise, which could lead to focused joint activities.

R. Molinari, the new Director of the CLIVAR IPO, provided a high-level overview of CLIVAR activities and discussed potential synergies with SPARC. It became clear that, particularly concerning monsoons, there will be opportunities for future cooperation between the two WCRP core projects.

V. Eyring reported on activities of the WGCM (Working Group on Coupled Modelling) related to the IPCC AR5. Within WGCM, standard experimental protocols for studies of coupled ocean-atmosphere general circulation models were developed through CMIP. It was noted that NASA is facilitating the use of its observational data

for the AR5 by proving a "users' guide" and making the data available in a form similar to model data, analogous to the work being done by the SPARC Data Initiative for the Ozone Assessment. V. Eyring also presented the input of SPARC to the WGNE/WGCM climate model metrics panel, which will come from experience gained in CCMVal.

T. Shepherd spoke about the ESA-SPARC initiative and the SPARC measurement requirements document requested by ESA to support this initiative. The ESA programme "Support to Science Element (STSE)" is aimed at developing "science partnerships" through strategic links with major international scientific programmes in order to enhance the international use of ESA and "ESA Third Party" (*e.g.*, Canadian or other European) data. Such collaborations already exist with other WCRP core projects (GEWEX and CliC) within a broader ESA-WCRP cooperation agreement, and with other international programmes, such as iLEAPS (Integrated Land Ecosystem-Atmosphere Processes Study) and SOLAS (Surface Ocean Lower Atmosphere Study). These collaborations are funded in response to requirements documents produced by the scientific community. In this way, ESA is allowing its investments in data set development to be driven by the needs of the relevant international user communities. In response to a request from ESA in spring 2010, a workshop was held in October 2010 in Zürich which was attended by representatives of the five SPARC activities engaged in analysis of satellite observations: ozone profile trends, water vapour trends, temperature trends, stratospheric aerosols, and the SPARC Data Initiative. This choice was made in light of the tight timeline for launching the first phase of the ESA-SPARC initiative. The workshop participants produced a draft "measurement requirements document" to move forward on its initiatives, which was presented at the SSG meeting, approved in principle, and finalized shortly afterwards, before being submitted to ESA. This document will drive work packages through the ESA STSE.

The first phase of the ESA-SPARC initiative is expected to last for two years, likely followed by subsequent phases in which more complex uses of ESA data could be considered. The discussion at the SSG meeting also highlighted the value of this sort of user-driven assessment for other observational data as well, not only from other space agencies but also from ground-based networks. It was decided that the next SPARC SSG meeting should include a longer and more wide-ranging and broadly-based discussion of SPARC measurement needs.

Geoengineering

A. Robock presented a comprehensive overview on geoengineering ("Smoke and mirrors: Is geoengineering a solution to global warming?"), which has a large visibility in environmental politics, but is also an increasing component of scientific research (it will figure in several chapters of the IPCC AR5). The term was introduced in the atmospheric science community by Paul Crutzen and Tom Wigley in 2006, when they suggested the idea of temporary geoengineering as an emergency response against climate warming. They suggested that cooling of the Earth's surface might be achieved by artificial injection of sulphur dioxide into the lower stratosphere, mimicking the effect of volcanic eruptions, which have had a demonstrable cooling effect on climate. Today, a variety of possible methods are discussed as "geoengineering". However, risks (depending on the individual method) might include: regional climate change, including a global reduction of precipitation with regional droughts; rapid reversal of the cooling effect when the application is stopped; continued ocean acidification; ozone depletion; effects on plants by changing the partitioning between direct and diffuse light; and unknown impacts on cirrus clouds. Even if the risks would be judged to be acceptable, the technical feasibility of any particular method needs to be ensured and the costs need to be properly quantified. T. Peter presented new results regarding geoengineering related to injection of sulfur dioxide into the stratosphere, taking into account the problem of enhanced stratospheric ozone depletion. Several modelling groups within the SPARC CCMVal community are currently engaged in studies of geoengineering. A. Robock described the geoengineering model inter-comparison project that he is leading (GeoMIP) within the context of CMIP5 (although not formally part of it). He encouraged the participation of the SPARC community, especially to focus on the impact on stratospheric ozone. The SSG welcomed GeoMIP as an official SPARC activity.

The future of SPARC

G. Asrar (Director of the WCRP JPS) chaired a panel discussion on the future of SPARC. This included a discussion of whether SPARC should change its name. This topic is covered in more detail in a separate article elsewhere in this issue.

SPARC infrastructure and upcoming meetings

SPARC gratefully acknowledges the generous support for the SPARC International Project Office from the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS), the Canadian Space Agency, Environment Canada and the University of Toronto. After 8 years, however, the SPARC office now is in the process of moving from Toronto (Canada) to Zürich (Switzerland) because of a lack of continued funding resources in Canada with the demise of CFCAS, which has been the primary sponsor of the Toronto office. For the new office in Zürich, SPARC has been fortunate to have obtained financial support from ETH Zürich, MeteoSwiss, and the Swiss Federal Office of the Environment. 2011 is the transition year during which the office in Toronto will remain operational, while the office in Zürich gradually builds its capabilities, to ensure a smooth handover.

Norm McFarlane was the Director of the SPARC office in Toronto for many years. T. Peter thanked him on behalf of SPARC for his continuous, altruistic efforts, his enthusiasm and his wisdom. Norm McFarlane resigned as office director at the end of the SSG meeting and passed the responsibility on to Johannes Stähelin.

The next SPARC SSG meeting is planned to take place in Zürich in early 2012.