SPARC

STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE

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Report on the 16th Session of the SPARC Scientific Steering Group

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The 16th Session of the SPARC Scientific Steering Group (SSG) was held at the University of Toronto and hosted by the SPARC Office. The main focus of this session was on the future of SPARC, taking into account the outcomes of the 4th SPARC General Assembly and new developments within SPARC's parent programme, the World Climate Research Programme (WCRP), over the past year.

T. Shepherd, Co-Chair with T. Peter of the SSG, welcomed the participants and briefly discussed the main issues to be addressed during the meeting. During the past year a comprehensive review of the WCRP by its sponsors was carried out,[1] and a draft was sent to the WCRP core projects, panels and working groups for their consideration and input for the WCRP response. The final version of the review is expected to be published in 2009. In addition, the WCRP is currently developing a new implementation plan that looks to the future of climate science in the next decade and beyond. This action is the result of deliberations undertaken at the most recent JSC meeting in Arcachon, France (see the report on JSC Session 29 in SPARC Newsletter No. 31), but issues raised by the WCRP review must also be taken into consideration when developing this new plan. SPARC input to the plan was needed by the middle of December 2008. The SPARC SSG meeting provided a valuable and timely opportunity for the SSG and SPARC activity leaders to assist in formulating the SPARC input for the response to the draft of the WCRP review and, at the same time, to provide input to formulating the SPARC component of the Implementation Plan.

Highlights of the 4th SPARC General Assembly

The SPARC General Assemblies, which are held every 4 years, are high quality international conferences that have become a key forum for presentation and discussion of new SPARC science, and timely surveys of key developments in the main areas of current and emerging research. The 4th SPARC General Assembly (GA) was held at the CNR Conference Centre in Bologna, Italy from August 31 to September 5. The venue and arrangements put in place by the Local Organising Committee (co-chaired by E. Manzini and S. Corti) were excellent, and the conference continued the tradition of previous SPARC GAs in that it was well attended and attracted a large number of young scientists and scientists from developing countries.

P. Haynes, co-chair with T. Peter of the Scientific Organising Committee for the 4th SPARC GA, summarised highlights at the SSG meeting. These are discussed in

[1] This review was carried out by a Review Panel appointed by WCRP's sponsors ICSU (International Council for Science), WMO (World Meteorological Organization) and IOC (Intergovernmental Oceanographic Commission) of UNESCO, together with IGFA (International Group of Funding Agencies for Global Change Research). The review was undertaken in parallel with a review of the International Geosphere-Biosphere Programme (IGBP).

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ICSU International Council for Science
IOC

more detail in an article in this issue of the SPARC Newsletter. The presentation and ensuing discussion affirmed that the 4th GA was a great success with a total of 335 registered participants, 49 of them from countries with developing/transitional economies (~50% more than for the 3rd GA), and strong participation by young scientists. The SPARC GA was held back-to-back with the International Conference of IGAC, the International Global Atmospheric Chemistry project of the IGBP (September 8-12 in Annecy, France). About 30 scientists made use of this special arrangement, and took advantage of the special offer of reduced fees for a 2-day participation in the sister conference.

Also raised was the issue of the recurring conflict with the Quadrennial Ozone Symposium (QOS), which is inherent in the four-year period adopted by both SPARC and the the International Ozone Commission (IO3C). It was agreed that moving one year out of phase would not work, as that would then clash with IUGG and IAMAS, which are major meetings for SPARC-related science. An attractive option is two years out of phase with the QOS, which would keep open the possibility of back-to-back meetings with the IGAC International Conference. However, it is already too late to plan a GA for 2010, so the idea emerged of holding the next GA in three years – but half a year out of phase with IUGG – and the next one three years after that, in order to reach this point. This option would have the added benefit of meeting more frequently during a time of rapid evolution of SPARC and the WCRP.

WCRP Update

The WCRP leadership and management were well represented at the SSG meeting with **G. Asrar** (WCRP Director) and **V. Ryabinin** (Senior Scientific Officer of the WCRP Joint Planning Staff) attending the entire SSG meeting, and **T. Busalacchi** (Chair of the WCRP Joint Scientific Committee) present for the second day. T. Busalacchi noted some key issues for the WCRP, *e.g*. the importance of a response by SPARC to the WCRP review and input to the Implementation Plan mentioned above. He also pointed to the upcoming World Climate Conference–3 (WCC-3), an event that will be of great importance for the future of the WCRP, and of climate science in general. (The WCRP itself was brought into being following WCC-1.)

The 2008 JSC meeting identified two important time periods in the future development of the WCRP: 2008-2013 and post-2013. During this period a major goal is to implement the WCRP Strategic Framework - the Coordinated Observation and Prediction of the Earth System (COPES) - which represents several years of intensive thinking on the role and workings of the WCRP. During this period, the WCRP must also prepare for changes in structure that may be required for the post-2013 period. In addition to maintaining some key structures and addressing key emerging science issues, the WCRP must become more effective in interfacing with users of climate information. Changes in WCRP structure and its strategic planning may be needed to meet these challenges.

T. Busalacchi stressed that the WCRP will always be focused on research, and G. Asrar emphasised that any change in form must be driven by function, and that grass-roots input from the WCRP core projects in developing the implementation plan is of great importance. The COPES framework includes a range of cross-cutting initiatives and activities, many of which are being addressed by the SPARC themes and activities. Reassurance that the COPES framework would not usurp the core projects was welcomed by the SSG. The COPES implementation plan must be completed in draft form for the next JSC meeting to be held in April 2009.

Discussion on the Future of SPARC

The stage for the discussion of the future of SPARC was set at the 4th SPARC GA in a presentation by T. Shepherd entitled "SPARC – Quo Vadis?" Additional comments by T. Busalacchi and G. Asrar provided context for the lively discussion that took place in separate sessions over the course of the SSG meeting. While it is clear that the WCRP will remain fundamentally focused on climate research, it will increasingly be called upon to address the growing demands for more information to meet the challenges of the societal impacts of climate change.

With regard to the future of SPARC, the SSG discussed SPARC's contribution to the COPES implementation plan. G. Asrar indicated that early input from SPARC is needed to address three key science questions in the implementation plan, namely:

(1) What will be the key science issues SPARC aims to address over the coming years to 2013?
(2) What elements of this science need to be taken forward beyond 2013?
(3) What new science should the WCRP address beyond 2013 in the context of SPARC?

Similar questions were posed to the other WCRP core projects at the 2008 JSC meeting in Arcachon. The response given by the SSG after the JSC meeting is provided in the SPARC legacy document.

The discussion on the future of SPARC initiated at the GA was, in part, motivated by the desire of the Co-Chairs and the SSG to engage the broader SPARC community concerning the future of SPARC. As promised during the discussion at the GA, the **SPARC Café** has been set up as an on-line bulletin board to facilitate this community-wide discussion.

The future of the SPARC Office: As noted at the GA discussion and in the JSC report in SPARC Newsletter No. 31, the major part of the current funding to support the SPARC Office in Canada, provided by the Canadian Foundation for Climate and Atmospheric Sciences, will cease at the end of the 2010 calendar year with no current prospect of renewal. In addition, N. McFarlane plans to step down as Director at the end of 2009. A number of options for the future of the SPARC Office were brought forward in the discussion and will be followed up by the Co-Chairs in collaboration with SSG members who volunteered to help.

The SPARC Themes

Detection/Attribution/Prediction

W. Randel provided an update concerning the ongoing work of the Temperature Trends Assessment Group. The recent work of the group is summarised in a paper now in press (Randel *et al.*, 2008). Current reanalysis and radiosonde records have both been problematic in estimating stratospheric temperature trends, however there is reasonable agreement between trend estimates from satellite data and radiosonde data, once instrument changes and the effects of CO_2 changes on the SSU weighting functions are taken into account. Water vapour

SPARC SSG meeting participants

variations in the tropical lower stratosphere evaluated from satellite observations (HALOE and MLS) are well correlated with temperature variations at the cold point tropopause. During the last decade temperatures in the lower stratosphere have been relatively constant. Possible causes for this will be investigated in the future. Other future activities will include detailed comparisons of CCMVal runs with updated observations. A further meeting of the group is planned to take place in the first half of 2009.

E. Manzini summarised recent research on decadal prediction from the perspective of the SPARC community. (See also the article on this topic by Keenlyside *et al*., in SPARC Newsletter No. 31). The issue of decadal predictability and prediction is relevant for SPARC because the stratosphere exhibits decadal variability associated both with internal processes (*e.g*. sudden stratospheric warmings and the quasi-biennial oscillation (QBO)) and with responses to external forcings (such as decadal-scale variations in solar irradiance, volcanic eruptions, and anthropogenic effects such as ozone depletion/recovery and increased GHG concentrations), and the relevance of teleconnection pathways that couple stratospheric and tropospheric variability is now recognised in regard to tropospheric predictability. In addition, there is a societal motivation for decadal prediction since this is the typical planning time scale for changes in infrastructure that may be needed to prepare, for example, for the impacts of climate change.

Modelling the role of stratosphere-troposphere coupling for decadal scale prediction poses a number of issues that SPARC can and is addressing. The importance of changes in atmospheric composition is of course central to the SPARC CCMVal activity. In addition, understanding and modelling physical and dynamical variability and its role in decadal prediction includes a range of modelling issues, such as the importance of horizontal/vertical resolution and vertical domain, and the role of parameterization of unresolved processes (*e.g*. gravity-wave drag) in modelling stratospheric variability. Many of these issues are addressed in the context of the DynVar activity.

S. Corti gave an overview presentation on seasonal prediction. Given that predictability from initial states is typically limited to periods of the order of 10-14 days, the accuracy of seasonal forecasts relies on lower frequency signals/forcing in the climate system. For example, in the tropics, enhanced predictability is associated with ENSO events, and this contributes to the relatively higher skill of seasonal forecasts in the tropics. In contrast, seasonal forecasting in regions where there is relatively high synoptic scale variability is typically not very skillful. However, there are some extratropical influences from events such as El Niño that may provide some skill.

Time scales and memory in the stratosphere are typically longer than in the troposphere and studies have shown that circulation anomalies in the stratosphere may propagate down into the troposphere on time scales of several weeks (Baldwin and Dunkerton, 2001; Baldwin *et al*., 2003). Current forecast models, even those that extend into the stratosphere, typically show systematic errors, such as underprediction of the stratospheric jet, that may be associated with inadequate resolution and modelling of stratospheric circulation anomalies and their downward influence.

K. Rosenlof presented an update on the SPARC Water Vapour Assessment (WAVAS-2) activity. This new activity was proposed at the previous SSG meeting (see C. Schiller *et al*., in SPARC Newsletter No. 30). The SPARC Water Vapour Assessment Report was published in 2000 (SPARC Report No. 2). Since then, many more satellite measurements have been made, and reprocessing of past satellite measurements has occurred. There has also been continual evaluation of discrepancies with *in situ* data; questions have been raised in regard to extremes in existing data (the so-called supersaturation puzzle); chemistry/climate models have improved to the point where they are better at simulating UTLS water vapour; and lower stratospheric trends have reversed - the consequences of which have not been thoroughly explored from a radiative and chemical standpoint.

The WAVAS-2 activity is co-chaired by C. Schiller, K. Rosenlof and T. Peter. A major outcome of the activity is expected to be an updated WAVAS report that summarises findings and recommends future directions. A SPARC sponsored workshop will be held in Toronto, Canada in March 2009 to identify and discuss the relevant issues and facilitate the formation of working groups to address them. Focus themes for the workshop are *in situ* data quality (AquaVIT), the supersaturation puzzle, data quality and merged (remote sensing) data records (stratosphere and UTH), and development of a modelling strategy for UTLS water vapour studies.

Stratosphere-Troposphere Dynamical Coupling

M. Baldwin presented a brief overview of activities in the last year that were relevant to this theme. Apart from the 4th SPARC

GA, the Chapman Conference on the Role of the Stratosphere in Climate and Climate Change, co-sponsored by SPARC, was another major conference within the past year that dealt with a range of topics within the general scope of the Stratosphere-Troposphere Dynamical Coupling theme (see Baldwin *et al*., SPARC Newsletter No. 31). A review paper on this topic is in preparation for Reviews of Geophysics.

While there is much active research in stratosphere-troposphere coupling, ensuring that contributions from it are represented in forthcoming WMO/UNEP and IPCC assessments continues to be an important issue for SPARC.

S. Yoden summarised recent work on dynamical aspects of stratosphere–troposphere coupling. Funding has recently been obtained for a new research project entitled "Assessment of the Stratospheric Effects on Climate Change and Elucidation of the Dynamical Role." This project includes co-investigators from several Japanese institutions and will involve collaborations with international groups. In addition to this new research project there are a number of ongoing research activities in Japan on a range of topics relevant to stratosphere-troposphere coupling. Recent examples are studies on the influence of tropical features (*e.g*. QBO and solar forcing) on the winter polar vortex, and studies on the tropospheric impact of stratospheric reflection of planetary waves.

P. Kushner summarised recent progress in the DynVar Activity. There has been steady progress since the initial planning report (see Kushner *et al*., SPARC Newsletter No. 29), and a follow-on planning workshop was held in Toronto in March 2008. This workshop has set the stage for DynVar activities for the coming 2-3 years. Work on several of the DynVar activity areas is under way and some relevant new research results are emerging. (See the article by Kushner *et al*., in this issue of the newsletter).

Chemistry-Climate Coupling

A. Ravishankara reviewed the development and timelines for the WCRP/IGBP Activity on Atmospheric Chemistry and Climate (AC&C), which is being carried forward jointly by SPARC and IGAC. Activity plans developed following the groundwork laid over the 2006-2007 period, notably by the initial scoping meeting (August, 2006), and the first AC&C workshop (January, 2007). Liaisons with existing ongoing activities were developed (*e.g*. AeroCom, CCMVal, ACCENT, HTAP). Details of modelling activities and engagement with all of the modelling groups involved were finalised in the first half of 2008, and from June to November, the AC&C Steering Group members have been working with the New Scenarios group to define emissions for AR5.

Model runs will be carried out in the coming year and preparation of publications will get under way. The modelling activity builds upon existing projects (CCMVal, AeroCom), and a new activity, TropChem, will augment and build upon the ACCENT Model Intercomparison Project and the HTAP (Hemispheric Transport of Atmospheric Pollutants) project. The AC&C activity has been generally successful in meeting its time lines and fulfilling its objectives, although it has faced a number of challenges, including limited human and computer resources, funding for travel, and ensuring that it is resonating with both the science community and the funding agencies.

Important issues for AC&C concern its future role and leadership. The importance of the SPARC role in AC&C was noted. Ongoing concerns are not only the contributions of SPARC to AC&C but also the benefits that SPARC receives from it (*e.g*. augmenting CCMVal contributions to the WMO/UNEP Ozone Assessment and AR5).

T. Shepherd summarised CCMVal development and activities. The CCMVal project has evolved substantially from its initial conception. CCMVal played a major role in the 2006 WMO/UNEP Ozone Assessment through its coordination of the CCMVal-1 reference simulations that were used in support of the assessment, and also contributed to IPCC AR4. Planning for CCMVal-2, which will provide similar and enhanced contributions to the 2010 WMO/UNEP Ozone Assessment and AR5, was initiated at the 3rd CCMVal workshop in Leeds in 2007 (see Eyring *et al*., SPARC Newsletter No. 30). There are now 20 modelling groups involved in CCMVal-2 – an increase from the 13 groups that participated in CCMVal-1. Currently, 65 CCMVal collaborators are working with output that is available on an open access basis from the model archive (see Guidelines for CCMVal Collaborators at **http://www.pa.op.dlr.de/CCMVal/**). Several papers have been published or submitted, and others are in preparation.

Planning for the SPARC CCMVal report began at the 3rd workshop, and it is now well under way with a target publication date in early 2010 in time to be available for the next WMO/UNEP Ozone Assessment. The overarching goal of the report is to improve understanding on the representation of key processes in CCMs. To that end it will look at radiation and chemistry, in addition to transport and dynamics. Observations will be key for the success of the report, and the report will help identify observational needs. The report will aim to develop quantitative performance metrics (extended from Waugh and Eyring, 2008).

The SPARC initiative on the role of halogen chemistry in ozone depletion was proposed and endorsed at the 2007 SSG meeting. The main objectives of the initiative are to (a) evaluate consequences of new data on the ClO dimer photolysis rate, (b) evaluate laboratory results for the photolysis rate, and determine further studies that are necessary to resolve current differences, and (c) assess evidence linking ozone depletion to stratospheric active chlorine/bromine amounts. **M. Kurylo** reported on progress during the last year. A workshop was held in Cambridge, UK in June 2008, which focused on laboratory/theory studies, atmospheric measurements, and modelling/analysis investigations (see Kurylo *et al*., in this newsletter). A special journal issue (TBD), on a time scale suitable for use in the 2010 UNEP/WMO Ozone Assessment, is planned.

A. Ravishankara also discussed the role of laboratory studies. The old paradigm, which was to isolate individual reactions for detailed study to isolate rate-limiting steps, must be replaced by one that considers complex mechanisms. It was agreed that this activity should be rejuvenated within SPARC. Scientists who could lead this activity will be considered.

G. Bodeker reported on the outcomes from two SPARC workshops — one on Ozone Recovery, held in Boulder in May 2008, and the other on the Ozone Data Base, held in Bologna in conjunction with the 4th SPARC GA. Companion articles summarising the key issues and outcomes of these meetings are available in this issue of the newsletter.

The Ozone Recovery Workshop was held to:

- redefine what is meant by ozone recovery, whether non-attributed (when ozone reaches pre-1980 levels) or attributed (when ozone concentration is no longer affected by the Ozone Depleting Substances (ODSs)),
- develop an improved framework for the next WMO/UNEP Ozone Assessment,
- generate a publication that describes this new framework for ozone recovery.

The Ozone Database workshop was convened to address the disparities in specifying past ozone forcing in the models that contributed to IPCC AR4. The goal of the workshop was to discuss the creation of a new ozone database, or a suite of databases, that will meet all of the needs of modellers, based on observations (see the report by Bodeker *et al*., in this newsletter). Substantial progress has been made since the workshop. A paper is underway, with a projected completion date by the end of 2008. The database will be made available to the CMIP5 community under the auspices of the WGCM, and possibly made available through the SPARC Data Center.

Cross-Cutting Issues

Polar Initiative

The role of the polar regions in climate was raised by SPARC at the 2008 JSC meeting as an important cross-cutting issue for the WCRP in the near future. A. Ravishankara reviewed the issues and progress on this initiative. Detectable climate change is occurring significantly earlier in the polar regions than in other regions of the earth, and these changes are separable from natural variability. These changes are taking place in the context of decreasing concentrations of ozone depleting substances and increasing concentrations of greenhouse gases. There are connections between different components of the Earth System that are driving these changes.

The WCRP, through its core projects, has all of the key components and expertise to address these issues. The decision of the JSC, as written in its report, was to: "Form a WCRP-wide group (from projects and WGCM) with involvement of IGBP representative(s) to work, initially by correspondence, on a topic of climate and polar regions, to scope the scientific issues pertaining to this topic (including predictability of Arctic, relevant biogeochemical processes), and present to the next JSC session a proposal for a WCRP way forward in this area. Recommend an effort aimed at using IPY results and other available knowledge and capacity to undertake an assessment of polar predictability at various time scales." A first step toward carrying the initiative forward within SPARC was taken in a small meeting convened at the GA. In this meeting, a list of potential members of a scientific committee was assembled, and timing, possible locations and themes for a focused workshop were suggested. At the SSG meeting it was decided to prepare a concept proposal for consideration by the JSC at its meeting in April 2009.

The Modelling Summit

E. Manzini reported on the World Modelling Summit for Climate Prediction that was held in May 2008, and hosted by the European Centre for Medium Range Weather Forecasts (ECMWF). This event was cosponsored by the WCRP, the World Weather Research Programme (WWRP), and IGBP. The World Modelling Summit was motivated by the perception in the climate science community that more rapid progress is needed in climate modelling in order to respond adequately to societal needs for the information that underpins decisions on adaptation to climate change and mitigation of its effects. The intent was to address the question of whether a radical new strategy for climate prediction is necessary and possible. The main tangible outcome of the Modelling Summit is the BAMS article entitled "A revolution in climate prediction is both necessary and possible," which includes the Summit statement and a proposal for an international climate prediction project. However, a number of issues of particular interest to SPARC raised at the Modelling Summit are discussed in an accompanying article by Manzini *et al*., in this issue of the newsletter.

Geoengineering

T. Peter reported on the discussions on geoengineering subsequent to those that first took place at the 2007 SSG meeting (see SPARC Newsletter No. 30). This topic was also put before the JSC in the SPARC presentation at its 2008 meeting. In the meantime some additional studies have been done and others are under way that are relevant to geoengineering proposals, such at that in the essay by Paul Crutzen (Crutzen, 2006). Recent examples include studies that deal with uncertainties in the stratospheric impact of volcanic eruptions (Kenzelmann, 2008). These uncertainties put into doubt present abilities to assess the effects of geoengineering proposals involving stratospheric aerosols. The discussion pointed to a number of possibilities for addressing scientific and policy issues concerning geoengineering. There are also related activities under way, planned by other organisations and individuals including forthcoming focused workshops. SPARC may be able to contribute to WCRP efforts through CCMVal by studying CCM responses to volcanic forcing. This issue will be passed back to the JSC for further action with recommendations for investigating the science underlying geoengineering applications.

The Gravity-Wave Initiative

A workshop on the Gravity Wave Initiative was held in Toronto in March 2008 in conjunction with the DynVar workshop, with a half-day joint session. Some interesting and provocative new results were presented at the workshop (See the article by M. J. Alexander in SPARC newsletter No. 31). Follow-on activities include preparation of a review paper summarising recent developments in the field, and a planned focused workshop early in 2009 to address mapping of global observational constraints on gravity-wave momentum flux sources. The review article is in preparation and planned to be published in the Quarterly Journal of the Royal Meteorological Society in early 2009.

M. Geller drew attention to an emerging issue concerning the archiving of high-resolution radiosonde data at the SPARC Data Center, supported by an NSF grant. It was recently discovered that the number of 6-second radiosonde data available from US stations has been decreasing because the National Weather Service is replacing the 6-second system with a 1-second system, a fact not widely known in the research community. The 6-second data have been widely used by the SPARC community, but the 1-second data will require additional processing. It may be desirable to process it further to produce a 6-second data set that is consistent with the previously archived data set. This will involve additional effort on the part of the Data Center. If this action is undertaken, should it be expanded to include archiving of world-wide high resolution radiosonde data? It was decided that a small working group would explore the information content of the 1-second radiosonde data and make recommendations concerning its use and archiving.

SPARC DA and SPARC-IPY

D. Pendlebury presented an update on the SPARC-IPY activity, which is to put together a well-organised data archive of measurements and analyses of the polar stratosphere during the IPY period. A substantial contribution to these objectives is being carried out under the auspices of the SPARC-DA activity. The collection and archiving of analyses has progressed as planned; data is being gathered for 6 DA systems (5 with ozone, 2 with other chemical constituents, 5 with water vapour). In addition, progress has also been made on the other main components of SPARC-IPY, namely the Pan-Arctic Study, and a range of outreach activities. The Pan-Arctic Study is aimed at better understanding the middle atmospheric circulation with the help of a network of Arctic lidar measurements, satellite measurements, and meteorological soundings and analysis. Outreach activities and interactions between SPARC-IPY research activities are being coordinated at the SPARC Office by E. Farahani.

SOLARIS and Solar Variability

K. Kodera reported on recent activities within the SOLARIS project. A side meeting was convened at the 4th SPARC GA to discuss the issue of the discrepancies in observed and modelled tropical solar ozone signals for the CCMVal-1 simulations (Austin *et al*., 2008). A series of new coordinated CCM experiments has been proposed to elucidate the impacts of QBO, solar and ENSO signals and their interaction in climate simulations. A SOLARIS meeting is tentatively planned for the second half of 2009.

M. Geller drew attention to the forthcoming review paper entitled "Solar Influences on Climate" (Gray *et al*.,) that is being prepared under the auspices of SCOSTEP/CAWSES. This review examines recent direct measurements and reconstructions of the solar signal in the more distant past when direct observations were not available. It concludes that recent reconstructions are still uncertain but indicate much smaller solar luminosity changes than earlier reconstructions did. It also emphasises that there is a consensus among solar physicists and climate scientists that climate change due to solar variations in the recent past were much smaller than those attributed to increasing greenhouse gas concentrations.

Update on the Tropopause Initiative

P. Haynes presented an update on the Tropopause Initiative which is being led by himself and A. Gettelman. Recent activities related to this initiative include involvement in recent and forthcoming special sessions on the UTLS and tropopause at the AGU and EGU. In addition, the SPARC Tropopause Web Site has been active for the past year (**http:www.acd.ucar.edu/sparctrop**). The key issues outlined in the white paper (see SPARC Newsletter No. 29) remain relevant and progress on them is being made. A review paper on the TTL (Fueglistaler *et al*., 2009) is in press. TTL transport issues and the role of deep convection are still subjects of active research. New work on the extratropical tropopause layer (ExTL) is under way aided by new observations and platforms and chemical measurements in the ExTL. Plans for future activities include organising UTLS sessions at future AGU and EGU meetings, and holding two focused workshops over the next two years: (a) UTLS observations and theory workshop, Boulder (October, 2009) and (b) AGU Chapman conference (or similar) workshop on the "Future evolution of the Tropopause" (likely in Spain, September, 2010).

Report on the WOAP meeting

The WCRP Observations and Assimilation Panel (WOAP) is co-sponsored by the Global Climate Observing System (GCOS). The WOAP members represent all WCRP core projects and working groups, as well as the WCRP/GCOS co-sponsored panels AOPC/OOPC/TOPC (Atmospheric/Ocean/Terrestrial Observation Panel for Climate). The 3rd meeting of WOAP was held in Boulder during September 28-October 1, 2008. During the past year, **C. von Savigny** was appointed as the SPARC representative to WOAP and attended the meeting on behalf of SPARC. The most important topics discussed were (a) progress achieved during the last two years in terms of observations, reprocessing and reanalysis, interactions between GCOS and WCRP activities, and participation in GEOSS; (b) transition of WCRP core projects and datasets beyond 2013, (c) assessment of the activities and results of the Task Group on Data Management and the Joint Working Group on Observational Data Sets for Reanalysis, (d) development of contributions to the WCRP implementation plan.

Some issues raised during the meeting that are relevant for SPARC include:

- ensuring the continuity of satellite capability for limb profiling for ozone and other relevant species, which is important to monitor the evolution and recovery of the stratospheric ozone layer
- the importance of restoring the climate instruments on NPOESS or other platforms
- the need to evaluate climate data sets, and to derive ECVs (essential climate variables), which are obtained by processing measurements from satellites or by combining measurements from various instruments.

Coordination with Other Agencies/ Programmes

The Third ACC Workshop on Long Term Data Sets and Climate Modelling

E. Hilsenrath summarised the role of the Atmospheric Composition Constellation (ACC) within the CEOS (Committee on Earth Observation Satellites) Agencies. The main objectives of ACC are to (a) establish a framework for long term coordination among the CEOS agencies, (b) collect and deliver data to improve predictive capabilities for coupled changes in ozone, air quality, and climate forcing associated with changes in the environment. The objectives of the workshop were to identify data gaps, review the status of on-going and planned research to develop Climate Data Records/Essential Climate Variables, review observational requirements for validation of CCMs and improved prediction, identify potential impact of data gaps on climate models, and to establish priorities.

One of the expected outcomes of the workshop is a report to the CEOS Agencies that will (a) identify gaps that are urgent and need immediate attention, (b) recommend longer term data and modelling studies that consider gaps or other data deficiencies, and (c) provide prioritisation of tasks. SPARC may contribute to this report. Immediate post-workshop plans include further updating of gap analyses, and recommendations to CEOS by the end of January 2009 to permit them to be considered in preparation for the GCOS meeting in early February. In the longer term, discussions with SPARC and IGAC on the implications of gaps must continue.

Other Agencies

S. Melo summarised the status of current and planned CSA (Canadian Space Agency) atmospheric satellite missions. Current operational missions of the CSA include MOPITT/Terra, OSIRIS/Odin, SciSat-1, and CloudSat. Most of the planned new missions will focus on tropospheric and near surface observations. However, of particular interest to the SPARC community is the SWIFT mission, currently in development, which will measure stratospheric winds, and the STEP (Stratosphere-Troposphere Exchange Processes) mission concept. The CSA now relies heavily upon both atmospheric modelling and ground-based stations to support its satellite missions. Models play a key role in mission development and exploitation of the data sets in realising mission science objectives. The CSA invests in model development through collaboration with universities *via* its grants and contributions programme, and other government agencies.

M. Kurylo reported on recent developments concerning the Network for Detection of Atmospheric Composition Change (NDACC). The 2008 meeting of the NDACC Steering Committee was hosted by the DMI in Kangerlussuaq and Ilulissat, Greenland from 25-29 September, 2008. The designation of measurement sites as “Primary” or “Complementary” has been terminated. See the short article on NDACC by Chipperfield *et al*., in the current newsletter for news on the NDACC. Also, a “Hot News” section will be initiated on the web site (**www.ndacc.org**).

G. Asrar briefly reviewed efforts to enhance collaboration between the WWRP and WCRP towards the development of routine climate prediction that would be on the same footing as weather forecasting. Their main objective is to develop the required infrastructure and make it accessible to the research community.

Update on the SPARC Data Center

S. Liess presented an update on the operation of the SPARC Data Center. The Data Center has been operational since 1999 at the Institute for Terrestrial and Planetary Atmospheres within Stony Brook University, New York, supported by grants from NASA. There have been recent hardware upgrades, with upgraded stability and security implementations. However, because of their very high storage space requirements, CCMVal data and SPARC-IPY data have been outsourced to the BADC (British Atmospheric Data Centre) and the University of Toronto, respectively. New hardware acquisitions are under consideration. Anticipated future services include installation of online plotting and downloading using NOAA’s Live Access Server software.

S. Liess has accepted a position at the U. of Minnesota and will be winding down his SPARC-related activities over the next few months. A suitable replacement will hopefully be found by March 2009.

Future SSG meetings, and closure of the 16th session

The 2009 SSG meeting will be held in Japan in conjunction with the IGAC SSC meeting. The likely dates are in the week of October 26-30, 2009. **P. C. S. Devara** has invited the SPARC SSG to hold its 2010 meeting at the Indian Institute of Tropical Meteorology in Pune, his home institution. He provided a short presentation to describe the excellent meeting facilities that are available at IITM. The Co-Chairs thanked Dr. Devara for his kind offer to host the 18th Session of the SPARC SSG.

The 16th session of the SPARC SSG was closed at noon on Thursday, November 13, 2008. The Co-Chairs were joined by G. Asrar on behalf of the WCRP in thanking the local hosts for the meeting arrangements, and the participants for contributing to a very productive session.

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Report on the 4th SPARC General Assembly

31 August – 5 September 2008, Bologna, Italy

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The Credo of SPARC General Assemblies

The 4th SPARC General Assembly provided an interdisciplinary venue for the exchange of scientific ideas and information related to "Stratospheric Processes And Their Role in Climate." More than 330 scientists enjoyed this week in Bologna, one of Italy's most elegant and least discovered cities, known variously as la dotta ("the learned one"), la grassa ("the fat one") or la rossa ("the red one"). The local organising committee, E. Manzini and S. Corti (Co-Chairs), C. Cagnazzo, F. Fierli, M. Pantano and E. Palazzi, did a superb job in realising this enjoyment on all levels, from logistic aspects to social events. The General Assembly benefitted from the excellent auditorium, and light and spacious poster halls at the CNR Conference Centre in Bologna. Delicious Italian food and drinks were offered to lubricate the science.

SPARC General Assemblies provide a platform for people to interact, one-on-one, in small groups, and in oral sessions. Oral contributions were held in plenary sessions, *i.e.* without parallel sessions; however, SPARC General Assemblies have a particular emphasis on poster sessions. These provide an opportunity for in-depth discussions, offering plenty of time for meaningful scientific exchange to take place. In Bologna, three poster sessions served this purpose. During each session about 110 posters were presented, and each session comprised about 6.5 hours of viewing and discussion time, conducted in three 2-2.5 hour blocks. The availability of the posters for two days in the vicinity of the auditorium allowed people to look at posters outside of the dedicated poster sessions.

The plenary approach of the oral sessions allows a synthesis of information and ensures scientific exchange within and across boundaries of different scientific topics. The programme of oral presentations was divided into 6 daily sessions, as follows: Sunday: Opening and Cross-cutting Science Topics, Monday: Stratosphere-Troposphere Dynamical Coupling, Tuesday: Extratropical Upper Troposphere / Lower Stratosphere (UTLS); Wednesday: Detection and Attribution of Stratospheric Change; Thursday: Tropical Tropopause Layer (TTL), Friday: Atmospheric Chemistry and Climate (AC&C), with session titles interpreted with sufficient flexibility to allow a "home" for all the major scientific activities of SPARC.

Most of the poster and oral presentations can be downloaded from: **www.atmosp.physics.utoronto.ca/SPARC/SPARC2008GA/GA008home.html** and a very full picture of the General Assembly is available from there. The following report is a summary of perceived highlights. Where poster presentations are mentioned the abstract number is given to help the reader find the relevant presentation on the website.

Back-to-Back with IGAC

SPARC, a core-project of the WCRP, and IGAC, the International Global Atmospheric Chemistry project of the IGBP, are moving closer together. This can be seen most clearly in the cross-cutting activity Atmospheric Chemistry and Climate (AC&C), which has held a number of workshops over the past three years, commonly organised between SPARC and IGAC. To enable cross-participation of attendees of both conferences, the SPARC General Assembly and the IGAC International Conference were organised back-to-back. The IGAC Conference was held in Annecy, France during the week 7 to 12 September 2008 immediately following the SPARC General Assembly.

Within the SPARC General Assembly the Tropical Tropopause and the AC&C themes were purposely scheduled on the last two days, and participation in these two days of the SPARC General Assembly was offered to participants of the IGAC conference at a special rate. SPARC participants were offered the same bargain for participation in the first two days of the IGAC conference, featuring the topics "AC&C" and "Clouds". In the end, about 30 scientists took advantage of the back-to-back organisation.

Opening and Cross-cutting Science Topics

The General Assembly began with an Opening Lecture by **S. Solomon** 'From the IPCC Assessment to Current Research and Back: An Overview of Key Findings and Issues in the Stratosphere and UTLS'. She emphasised that many aspects of the stratosphere were important to the findings of the 4th IPCC Assessment Report and needed further investigation, not least because of the strong indications that the coupling between troposphere and stratosphere was important for regional climate change (which is the aspect of climate change of particular interest to policymakers). She noted the particularly strong connections between stratosphere and troposphere in the Antarctic, with possible implications for sea-ice changes.

Four further 'cross-cutting' talks covered areas of broad SPARC interest.

S. Polavarapu reported on recent progress in middle atmosphere data assimilation. Spin offs of improved assimilation have included better representation of chemical transport and estimates of middle atmosphere gravity-wave drag (*e.g.* **Pulido A167**). **U. Lohmann** discussed the need for better understanding of cirrus clouds, *e.g.* to interpret apparent trends and described recent implementation of supersaturation schemes in GCMs. In a broad-ranging talk on satellite observations, **J. Burrows** presented the last 50 years as a golden pioneering age for space-based remote sensing observations, with information on many chemical species now available, but asked whether the satellite observing systems planned for the future would be adequate, particularly for monitoring long-term changes in climate and assessing chemistry-climate feedbacks. Finally, **F. Cairo** reviewed some of the important results that have been obtained over the last decade by measurements from the M55 Geophysica aircraft, most recently in the West African AMMA campaign. He noted that in AMMA, as in previous campaigns, there was evidence, in limited geographical regions, of moist layers above the cold-point tropopause, with an identifiable link to recent overshooting convection.

Stratosphere-troposphere dynamical coupling

In the past 5-10 years, it has been widely recognised that "two-way" coupling between the stratospheric and tropospheric circulations is an important component of variability in the extratropical atmosphere. Despite clear evidence from observations and models that stratospheric processes impact surface climate, many key aspects of stratosphere-troposphere coupling have proven remarkably difficult to understand. For example, we still do not fully understand the processes whereby changes in the stratospheric flow influence the troposphere, nor do we fully understand how changes in the stratospheric flow influence the vertical propagation of waves from the troposphere, which act as a forcing for the stratosphere. Stratosphere-troposphere dynamical coupling is an important process across time scales ranging from days to centuries. The strength of the coupling means that improvements to stratospheric representation in models might lead to improvements in seasonal and climate time scale prediction for the troposphere, and information on the state of the stratosphere might be useful input to medium and longer-range weather forecasting.

The continuing interest in and importance of these topics was reflected in a wide variety of presentations at the General Assembly. **D. Thompson** discussed recent theoretical and modelling work on the effects of stratospheric wind and temperature anomalies on the troposphere, noting that this is a particular case of the general 'climate-forcing' problem of determining the tropospheric response to external perturbation and emphasising the importance of tropospheric eddy feedbacks.

One of the clear manifestations of coupling between stratosphere and troposphere is the deep vertical structure of the "annular modes" (AMs) of extratropical climate variability. The leading AMs in the troposphere are often found to dominate the response to forcing – be it generic climate forcing or forcing in the stratosphere. As noted by **P. Kushner**, the "fluctuation-dissipation theorem" offers one route to understanding this and predicts, for example, that the response to forcing will be larger when the time scale of the leading AMs, is longer. One recent finding is that this time scale is unrealistically long in some idealised models, implying that the tropospheric response to forcing is unrealistically large (although the value of the idealised models is in highlighting mechanisms rather than giving precise quantitative predictions). There were many presentations discussing these and related issues, including the importance of the eddy response in the stratosphere (as well as the troposphere) (**Chan A357**), shifting of critical latitudes as a way to understand changes in tropospheric eddy fluxes (**Chen A165**), interactions between different AMs (**Sparrow A230**) and the limits of the fluctuation-dissipation theorem (**Cooper A205**).

In a SPARC Lecture, **T. Palmer** discussed the concept of seamless forecasting on all time scales, and of using numerical weather prediction techniques to calibrate climate models. He noted two broad categories of uncertainty in model predictions: the large spread of uncertainty among models ("uncertainty of the first kind"), and common model deficiencies ("uncertainty of the second kind"). He noted that the stratosphere is potentially important on climate-change time scales, but so are other aspects of the climate system, including tropical ocean-atmosphere coupling, and changes to the cryosphere. It is important to clarify the relative importance of these different components – which may of course vary according to location and time scale.

There were interesting presentations on the effect of stratospheric representation in climate models, *e.g.* **Giorgetta (A196)** reported a careful comparison between high-top and low-top models, finding several differences between the two and concluding that many of these were as a result of the fuller representation of stratospheric wave mean-flow interaction in the high-top model. **Fletcher (A156)** reported a case where the high-top simulation was poorer than the low-top simulation, *(i.e.* a high-top is not a panacea), and **Sigmond (A367)** identified the primary influence of gravity-wave drag as setting the 'background state' for planetary-wave propagation.

One seemingly robust result from models with good stratospheric representation is that the strength of the Brewer-Dobson circulation will increase as greenhouse gases increase (*e.g.* Butchart *et al*., 2006), with a corresponding decrease in age-of-air. There is improved understanding of the mechanisms for this strengthening, though the mechanisms seem to vary from one model to another. **Deckert (A115)** identified increased generation of planetary waves in the tropics, particularly in the summer hemisphere, **R. Garcia** saw increased subtropical wave-driving in the lower stratosphere, perhaps due to increases wave generation in the tropics, or to increased propagation out of the extratropics (**Figure 1**, colour plate I), and **C. McLandress** saw changes to both planetary waves and (parameterized) gravity waves. But counter to the apparent consensus in models that the Brewer-Dobson circulation will strengthen in the future, and has strengthened in the recent past, **Möbius** (**A414**, paper to appear as Engel *et al*., 2009 in Nature Geoscience) described observational estimates that indicate an increase of age-of-air from SF_6 over the last 30 years, implying a decrease in the strength of the Brewer-Dobson circulation.

Significant interest continues in the influence of the solar cycle on the stratosphere and troposphere. Much of the general work on the response of the tropospheric circulation to external forcing is relevant here, and some studies have solar-cycle effects particularly in mind (**Simpson A153**). There has been substantial progress in simulating the influence of the solar cycle in comprehensive GCMs. **K. Matthes** presented results from a study with WACCM showing that inclusion of a forced equatorial QBO together with variable (*i.e.* not time-slice) solar cycle forcing was necessary to give good simulation of the seasonal evolution of the solar-cycle anomaly in the stratosphere. If these results hold for other models, it might help to explain the mechanism for the observed Labitzke-van Loon relationship among the solar cycle, the QBO, and polar temperatures.

Extratropical UTLS

The science presented under this heading fell, roughly speaking, into three subject areas: ice supersaturation in UT, chemical and dynamical processes in UTLS, and polar ozone chemistry. There was a broad range of research approaches including satellite and airborne observations, modelling and new laboratory measurements, reflecting the recent advances in technology.

The first invited speaker, **D. Murphy** presented a newly developed technique to analyse chemical composition of single particles in the region of UTLS. He showed that particles in the upper tropical troposphere are not primarily sulfuric acid, but have high organic content, which suggested a potential of ice nucleation. **P. Spichtinger** focused on internal dynamics of cirrus clouds. He used an anelastic non-hydrostatic model together with his original ice microphysics scheme, showing that the occurrence of cirrus clouds in the ice-supersaturated regions over the extratropics is strongly correlated to large-scale dynamics. In some cases, high supersaturations inside thick clouds could exist. Some related talks on ice cloud formation were also given in the TTL session.

There were some outstanding talks on stratosphere-troposphere exchange and dynamical mechanisms controlling chemical transport in UTLS. **T. Birner** gave an update on the tropopause inversion layer (TIL), the region of high static stability found just above the extratropical tropopause, which provides a new angle on the question "How sharp is the extratropical tropopause?" **M. Hegglin** presented recent results obtained from the ACE (Atmospheric Chemistry Experiment)-FTS. The main message from her talk was the value of satellite measurements in providing a global view of the chemical composition of the extratropical UTLS, whereas up to now most information has been obtained from balloons and aircraft. She extended our limited knowledge of stratospheric O_3-N_2O correlation to global scale and provided the first comprehensive data set for the investigation of interhemispheric, interseasonal, and height-resolved differences of the O_3-N_2O correlation structure.

Many other studies also applied new satellite data to investigate the distribution of chemical species and dynamical processes related to transport in UTLS. Sensors such as MLS (Microwave Limb Sounder) and HIRDLS (High Resolution Dynamics Limb Sounder) onboard EOS-Aura have provided useful data to understand ozone transport mechanisms (**J. Gille**, **M. Santee**, **J. Rodriguez**). The new satellite data is also providing potentially valuable information on gravity waves, giving the possibility of identifying wave sources (**J. Alexander**), and the three-dimensional structure of the waves (**T. Horinouchi).**

New aircraft measurements were also highlighted. **H. Bönisch** reported simultaneous *in situ* measurements of CO_2 and SF_6, which were taken in the extratropical UTLS for the time period 2000 - 2003 during the SPURT (SPURenstoff-transport in der Tropopausenregion) project. His study gives useful information on the time scale of troposphere-to-stratosphere chemical transport, and for validating of chemical transport models.

Another outstanding topic was on the impact of new laboratory measurements on polar chemistry presented by **M. Rex**. New laboratory work by Pope *et al.* (2007) on the cross-sections of ClOOCl suggests that the photolysis of ClOOCl under polar stratospheric winter/spring conditions is nearly an order of magnitude slower than what would be required to explain the observations of ozone loss and ClO in the atmosphere. As reported by Rex, in most chemical models, the ozone loss rates calculated based on the known ozone loss mechanisms become much smaller than estimated from observations. If the cross-sections reported by Pope *et al.* (2007) are correct, a major fraction of observed polar ozone loss is due to a currently unknown mechanism. This indicates "a major challenge of our fundamental understanding of the polar stratospheric ozone loss process". (See also **Harris A266** and **Chipperfield A425**.) A SPARC initiative, "The Role of Halogen Chemistry in Polar Ozone Depletion" has been set up to deal with this issue, and work continues to resolve the discrepancy between laboratory data and observational results.

Polar stratospheric clouds also have a critical role in ozone destruction. An innovative technology from space-based lidar, CALIOP (Cloud-Aerosol LIdar with Orthogonal Polarization), provides a fantastic picture of spatial distribution of polar stratospheric clouds with their microphysical information (**M. Pitts**). It is desirable that such advanced observations will continue into the future.

Detection and Attribution of Stratospheric Change

The concepts of detection and attribution have become central to the discussion of the recovery of the ozone layer. Detection of statistically significant changes in ozone tendency, based on analyses of long-term high quality measurements, coupled with attribution of those changes to decreases in stratospheric halogen loading, forms the basis for the discussion of ozone recovery. To attribute changes in ozone unambiguously to changes in ozone depleting substances (ODSs) it is necessary to first quantify the effects of other factors that may affect ozone, such as changes in stratospheric temperatures or transport, the effects of the solar cycle, or changes in other chemical cycle, *e.g.* changes in HO_x cycles resulting from changes in stratospheric water vapour. Regression analyses, where basis functions describing the known geophysical forcings of ozone are optimally fitted to measured ozone time series, is a commonly used technique to quantify non-ODS effects on ozone (**Wohltmann A39**), and to detect trends in stratospheric composition and temperature (**Hassler A119**; **McDermid A45**). Because of the role that stratospheric processes play in climate, detection and attribution of stratospheric change becomes a part of the process of attribution of climate change (**Roscoe A18**). Without such attribution, quantifying the contribution of anthropogenic activities to observed and projected changes in climate is not possible.

A number of oral and poster presentations in this session focused on the topic of ozone recovery and understanding the interplay between the different processes affecting both the detection and attribution of ozone recovery (**P. Newman**). Detection of the first two stages of ozone recovery (reductions in the rate of decline and then increasing ozone attributable to decreases in ODSs) has been demonstrated in many locations in the atmosphere, and the emphasis has now shifted to better understand what processes will affect the long-term full recovery of the ozone layer, including the future evolution of equivalent effective stratospheric chlorine (EESC) and future trends in stratospheric temperatures. Because of the strong dependence of ozone recovery on changes in EESC, understanding and reducing the uncertainties in projections of stratospheric halogen loading was a key topic, see **Figure 2** (colour plate I).

Ozone recovery in turn drives long-term tendencies in stratospheric dynamics such as the final warming date in Antarctica (**J. Haigh**), and in surface climate such as the southern annular mode (SAM). It was shown that stratospheric ozone loss above Antarctica is 7 to 70 times more likely to be the cause of the observed increase in the strength of the SAM over the past 2-3 decades than greenhouse gases (**Roscoe A18**). Therefore, as the ozone hole recovers, the SAM should weaken (Perlwitz *et al*., 2008).

In the past a number of linear correlations between stratospheric variables have been empirically deduced, *e.g*. the V_{PSC} *vs*. ozone loss relation (Rex *et al*., 2004). Such relationships are useful in attributing inter-seasonal variability in the stratosphere but until we can quantitatively understand the linear behaviour of these relationships and their uncertainties (Jackson and Orsolini, 2008), we cannot be sure that they are applicable outside the range of parameters from which they were derived. A better understanding of the linearity of the V_{PSC} *vs*. ozone loss relationship has now been demonstrated (**N. Harris**).

The mechanisms underlying solar cycle variability in ozone, and the transmission of the solar signal to lower altitudes in the atmosphere, were discussed in a number of presentations (**L. Hood; Remsberg A76**). There is renewed interest in the effects of energetic particle precipitation, which, through ionization and dissociation processes, drives increases in NO_x and HO_x and increases ozone destruction.

A focal point for this session was the measurement of water vapour in the stratosphere (**O. Moehler**) and detection and attribution of long-term changes in stratospheric water vapour. It was shown (**M. Weber**) how observed changes in stratospheric water vapour can be linked to recent changes in the strength of the Brewer-Dobson circulation and lifting of the tropopause (**Van Malderen A118**), a link here to the discussion of dynamical changes in the Brewer-Dobson circulation in the stratosphere-troposphere coupling session. Time series of GPS radio occultation measurements are becoming sufficiently long to allow for detection of changes in stratospheric temperatures and water vapour (**D. Narayana Rao**).

Tropical Tropopause Layer

Study of the TTL (Tropical Tropopause Layer) has grown enormously in the past decade or so (see review by Fueglistaler *et al*., 2008a). Papers on TTL research have been highly visible at the previous two SPARC General Assemblies and in Bologna there were 11 oral presentations and more than 40 posters on this topic. Noteworthy observations in the TTL included convective influences over India (**Kulkarni A87**), a range of stratospheric and convective influence in upper troposphere and TTL ozone over La Reunion over the western Indian Ocean (**Clain A129**), black carbon in the TTL from flights out of Costa Rica (**Spackman A295**), MJO signatures over Indonesia (**Hermawan A106**), water vapour, clouds and supersaturation (**Voemel A430**), and QBO and ENSO signals in the TTL from SHADOZ (**Lee A280**).

Several invited talks highlighted complexities in understanding processes in the TTL, including reconciling observations with theory. For example, **L. Donner** focused on inadequacies of general circulation models for representing the sub-grid convective transport that redistributes species between the surface and upper troposphere, and on through the TTL.

Two comprehensive papers presented in the TTL session were a theoretical one on the UTLS diabatic heat budget of the TTL (**S. Fueglistaler**), and an observational study of TTL waves and cirrus using lidar and sounding data from tropical Pacific cruises (**M. Fujiwara**). Understanding the heat budget is crucial to transport processes at the tropopause. Given that there is significant cancellation between individual terms in the heat budget and that clouds are a major complication, accurate calculation of the budget is a challenge. Illustrations from various campaigns demonstrated the variable effects (positive or negative) in the vicinity of thick clouds. **S. Fueglistaler** also compared ECMWF analyses and reanalyses (ERA-40) with relevant diagnostics to illustrate deficiencies in present-day model evaluations of individual terms in the diabatic heating rate.

Before discussing the results of three western Pacific cruises, **M. Fujiwara** reviewed earlier TTL observations based on Indonesian ozonesonde-radiosonde measurements. Both equatorial Kelvin waves and breaking Rossby wave intrusions of mid-latitude air were detected and the observations confirmed with back-trajectories and models, as is corroborated by SOWER (Studies of Ozone and Water Vapor in the Equatorial Region, **F. Hasebe**). Similar processes contributed to temperature, wind and cirrus variability on three month-long R/V Marai cruises in early winter 2001, 2002 and 2004-2005. Observations interpreted with ECMWF analyses and back-trajectories indicated the presence of both "visual" and sub-visual cirrus at various times and four processes that appear to control cirrus. Two of these, convective (vertical) transport of water vapour and cloud particles, and advection of water vapour and cloud particles possibly associated with equatorial Rossby waves, were implicated in the relatively dense cirrus observed on the 2004-2005 cruise. This cruise featured fairly rapid quasi-steady diurnal variations in TTL cirrus that might point to an additional mechanism for TTL dehydration. (See **Figure 3**, colour plate II).

A worthy complement to the papers presenting cirrus and aerosol particle data in the TTL was **T. Koop**'s SPARC Lecture on microphysics and ice nucleation in various regimes. A theoretical framework for homogeneous and heterogeneous nucleation was provided, including, under certain circumstances, a role for a "glassy" aerosol phase. Data were supplied by field and chamber experiments (see **Figure 4**, colour plate III).

Atmospheric Chemistry and Climate

Since the last SPARC General Assembly in 2004, the Chemistry-Climate Model Validation (CCMVal) Activity has become the major chemistry-climate modelling initiative within SPARC. A summary of CCMVal-1 results was presented in a SPARC Lecture by **D. Waugh**. CCMVal defined the forcings and simulation protocols for the chemistry-climate model (CCM) reference simulations that provided a major underpinning for the 2006 WMO/UNEP Scientific Assessment of Ozone Depletion (WMO, 2007). The CCMVal-1 runs were analysed in community publications (*e.g*. Eyring *et al*., 2007) and were of critical importance in assessing the evolution of ozone, temperature, and trace species in the stratosphere in the recent past as well as in making projections of ozone recovery in the 21st century. The projected stratospheric ozone evolution in the 21st century on a global scale is mainly determined by decreases in halogen concentrations and continued cooling of the global stratosphere due to increases in greenhouse gases. Ozone is also affected by stratospheric circulation changes arising from climate change. For example, models consistently project a decrease in tropical lower stratospheric ozone associated with increased tropical upwelling. Such a decrease in lower stratospheric tropical ozone is in fact observed (Randel and Wu, 2007), but it is attributed to climate change, not to CFCs, and so is not expected to reverse in the future. Using the CCMVal-1 model simulation archive, Son *et al*. (2008) showed that the recovery of the Antarctic ozone hole should lead to a reversal of the observed Southern Annular Mode (SAM) trend over the next half-century. Such a reversal is not predicted by the IPCC AR4 models and even those with imposed ozone recovery did not predict as large a change in the SAM trend as was found in the high top CCMs (**Figure 5**, colour plate III). This demonstrates the importance of a fully coupled representation of ozone and climate in a stratosphere-resolving model. Elsewhere in this session a variety of related talks and posters were presented, including results from improved model versions that will feed into CCMVal-2, which is currently in preparation.

Stratosphere-troposphere exchange is a major source of natural variability in tropospheric ozone, and the inclusion of realistic time-varying ozone and a nudged QBO in the HADGEM1 model greatly increases the variability of parameters at the Earth's surface (**L. Gray**). **C. Mathison** showed how improved representations of ozone can lead to better temperature analyses and forecasts *via* more accurate radiative heating rates and better assimilation of satellite radiances. **K. Tourpali** presented surface UV simulations in the 21st century which used CCMVal-1 results as input to a radiative transfer model to calculate future UV irradiance levels under cloud free conditions.

Several contributions considered the tropical tropopause layer, which is important for the dynamics, radiation, and chemistry of the atmosphere. **T. Reichler** showed results from a model-based approach to investigate tropical tropopause trends in his talk. The tropopause height increases almost steadily during the 140 simulation years from 1960 to 2100 with the CCM AMTRAC. On the other hand, tropopause temperature shows a marked and climatically important transition near the year 2000 in this CCM, with cooling in the past and warming in the future. Using multi-linear regression, they showed that long-term trends in tropopause parameters can be fit with high accuracy to terms representing total column ozone, tropical mean sea surface temperatures, and tropical mass upwelling. The change in tropopause temperature trend near the year 2000 is related to the change in the sign of the stratospheric ozone trend.

Changes in tropospheric chemistry, their impacts on climate, and the effects of deep cumulus convection on atmospheric chemistry were presented in two invited talks by **K. Sudo** and **M. Lawrence**. A changing climate will change air quality and the tropospheric ozone budget has a role in climate change. The tropospheric ozone burden has increased by 71 Tg between 1890 and 1990 — an increase of ~30%. In the future climate, the decreased tropospheric burden will be the result of competition between increased ozone destruction due to higher relative humidity and increased influx of ozone from the stratosphere. Stevenson *et al*. (2006) showed that the different models participating in the PHOTOCOMP-ACCENT-IPCC model intercomparison study have different sensitivities to these processes. In polluted regions, climate change will have a positive feedback on surface ozone, whereas in clean regions, climate change will have a negative feedback on surface ozone. Deep cumulus convection has several important influences on atmospheric chemistry, such as vertical transport, scavenging of soluble gases and aerosols by precipitation, and generation of lightning, which produces NO. Deep convection also effects atmospheric chemistry indirectly through its contributions to solar and infrared radiation budgets, and to both synoptic and global scale circulations. Several key aspects were highlighted from simulations with the chemistry- transport model MATCH (Lawrence and Salzmann, 2008) and the CCM EMAC. This highlights issues relevant to chemistry of the UTLS region, which is important for the IGAC/SPARC AC&C Activity 2 concerning processes controlling vertical distributions of trace gases and aerosols.

SPARC 2008 Poster Awards

Kevin Grise (Colorado State University, Fort Collins, USA), Susann Tegtmeier (Environment Canada, Toronto, Canada) and Padmavati Kulkarni (National Atmospheric Research Laboratory, Gadanki, India) received SPARC 2008 Poster Awards for their outstanding posters presented during the 2008 SPARC General Assembly. The members of the scientific organising committee are grateful to these young members of the SPARC research community for helping to turn this conference into a wonderful success!

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SPARC Dynamics and Variability Project (DynVar): Plans and Status

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Introduction

In SPARC Newsletter No. 29, we introduced the SPARC Dynamics and Variability Project (SPARC DynVar), a model intercomparison project focused on the question of stratospheric influence on tropospheric climate. We here summarise the DynVar project plans for the next few years based on input from a workshop held at the University of Toronto, 27-28 March 2008, and from surveys of the DynVar participants. Further details and updates will be posted on the SPARC DynVar website, **www.sparcdynvar.org**.

Review and Update on DynVar Goals

The SPARC DynVar project aims to study the dynamical influence of the stratosphere on the troposphere using "high-top" atmospheric general circulation models (AGCMs) with good stratospheric representation. The project's long-term goal is to determine the dependence of the mean climate, climate variability, and climate sensitivity on the stratospheric general circulation as represented in AGCMs. It aims to answer the thematic questions posed in our article in SPARC Newsletter No. 29:

1. *How does the stratosphere (more specifically, the stratospheric general circulation as represented in climate models) affect the tropospheric general circulation?*
2. *How does the stratosphere influence climate variability on all time scales?*
3. *How does the stratosphere influence climate change?*

Within its scope, the project includes ocean models coupled to high-top AGCMs to investigate in a more realistic setting the two-way troposphere-stratosphere dynamical coupling. It also includes a theoretical component intended to improve our physical understanding of stratosphere-troposphere coupling. The project is complementary to and coordinated with other SPARC Initiatives, in particular SPARC CCMVal, SPARC SOLARIS and the SPARC Gravity Wave Drag Initiative. A strategic aim will be to provide a clear assessment on how important it is to simulate the stratosphere in climate-change simulations for future international climate assessments.

The project's main activity will be to analyse a database of AGCM simulations developed for the project. The requirements of the AGCMs, the simulations, and the analysis have been developed through the March 2008 planning workshop, and through participant surveys. The main focus will be on "high-top" AGCMs with a good representation of the stratosphere and with prescribed radiatively active gases. These will be compared to "low-top" AGCMs with poor stratospheric representation that most modelling groups have until now used for climate assessment. The project will not require participating models to include interactive chemistry modules or realistic simulation of solar influences. The minimum requirements for models in the project are outlined in the section entitled "AGCM Requirements" below.

DynVar will initially focus on "free-running" GCM simulations. This means that observations (other than standard boundary and radiative forcings) will not be incorporated within the standard simulations. Thus, this excludes from the current core DynVar effort 1) data assimilation based analysis and 2) initialisation from realistic atmospheric and oceanic initial states.

DynVar has several connections to other SPARC projects. First, DynVar has coordinated some of its planning efforts with the SPARC Gravity Wave Drag Initiative that is being lead by Joan Alexander (see SPARC Newsletter No. 31). As a result of this effort to coordinate plans, the GWD Initiative's first workshop was held in Toronto at the same time as the DynVar workshop and included a joint afternoon session for the two projects. Second, the SPARC CCMVal project developed plans for new simulations and data protocols in 2007; DynVar will coordinate its data and simulations sets with the new CCMVal plans and diagnostic efforts.

SPARC DynVar's organising group consists of the co-authors of the article describing the project in SPARC Newsletter No. 29. P. Kushner is the overall project coordinator, which is further sub-divided into four analysis areas, each with its own coordinators. The four analysis areas are: (A) "DynVar Top" (Coordinators: F. Sassi and M. Giorgetta), which addresses the influence of the stratosphere on the tropospheric circulation, on the ocean circulation *via* air-sea interactions, and on the cryosphere (in particular the sea ice field), apart from anthropogenic climate change; (B) "DynVar Intraseasonal (Coordinator: J. Perlwitz), which addresses issues of stratosphere-troposphere coupling on intraseasonal time scales; (C) "DynVar Climate Change" (Coordinator: E. Manzini), which addresses the role of the stratosphere in controlling the tropospheric circulation response to climate change; and (D) DynVar Ideal (Coordinator: L. Polvani), which is a cross-cutting theme that uses simplified models and more theoretical approaches to improve the dynamical understanding of stratospheric influences.

Anyone may join the DynVar project; to access DynVar data, researchers will need to become participants in the project. This is simply a matter of contacting Paul Kushner and filling out a survey to identify data and analysis needs and contributions. All project participants will need to agree to a data use policy that is based on the CCMVal data policy, which is described below. The current project participant list is on the DynVar website.

Requirements on AGCM Resolution and Configuration

The project will first focus on models that are of sufficient resolution to capture large-scale extratropical stratosphere-troposphere circulation features: baroclinic eddies in the troposphere, Rossby-wave breaking in the stratospheric surf zone, the vertical structure of extratropical planetary-scale waves propagating from the troposphere to the stratosphere, and stratospheric sudden warming events. We will not aim for models that realistically simulate solar variability or the QBO. At a minimum, participating high-top AGCMs should solve the primitive equations or the non-hydrostatic equations on the sphere, with a horizontal resolution that corresponds to at least T42 horizontal spectral resolution (3 to 4 degree resolution), and a vertical resolution of at least 35 levels, with the model lid and the model sponge layer located above the stratopause, which is located at approximately 1 hPa. The high-top models should also include parameterizations of the gravity wave influence on the large-scale atmospheric circulation. The low-top models used for low-top/high-top comparisons should satisfy the same horizontal resolution requirements but no additional requirements will be placed on their vertical resolution.

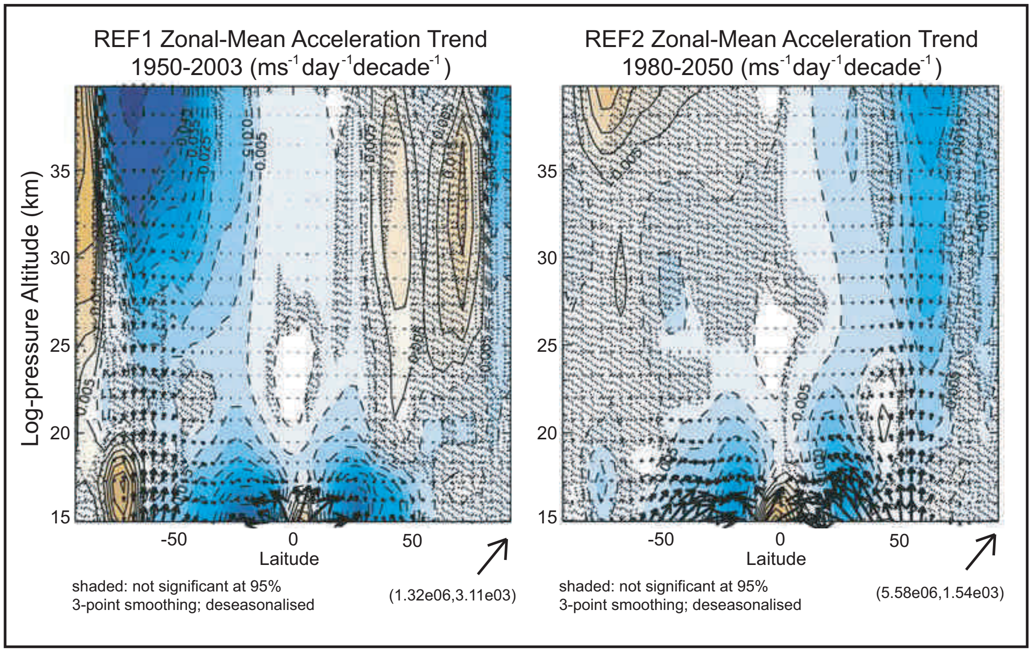
The project will require multiple realisations of multi-decadal simulations to ensure good sampling of stratosphere-troposphere signals. Each of the simulation sets described below will have prescribed boundary and radiative forcings that should be implemented in as consistent a manner as possible. Several of the simulations use CCMVal prescriptions as their starting point.

Proposed Simulation Sets

We plan to run and analyse a sequence of three simulation sets:

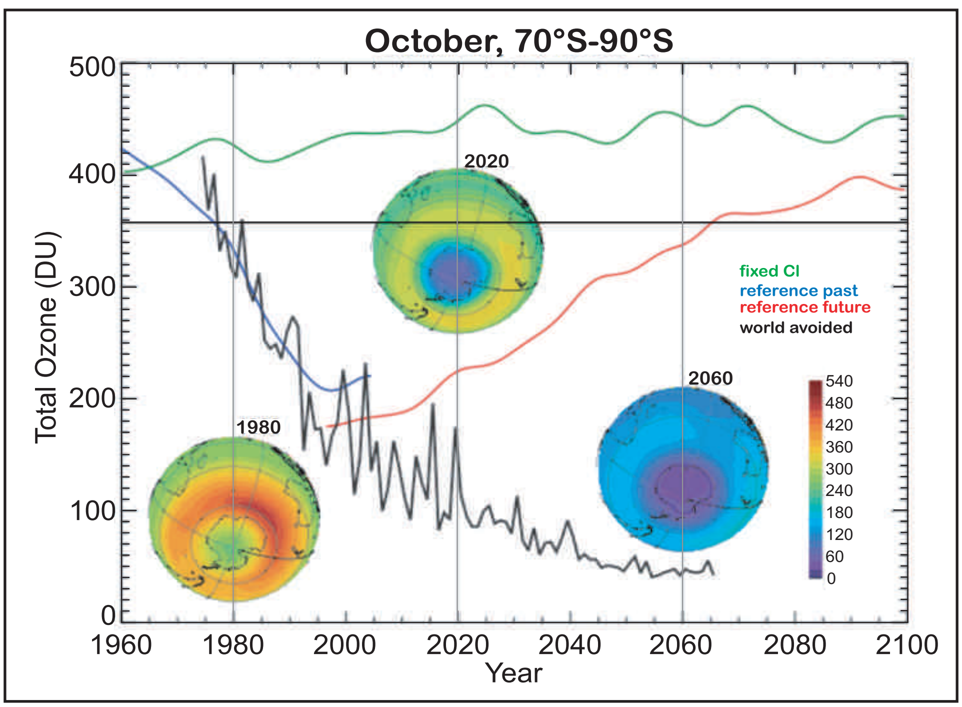
- *Simulation Set A* examines stratosphere-troposphere dynamics in the absence of coupling to the ocean (AGCM + prescribed SSTs)
- *Simulation Set B* examines stratosphere-troposphere dynamics in the presence of thermal coupling to the ocean (AGCM + slab mixed-layer ocean), examining standard $2XCO_2$ as well as the less well studied Gillett-Thompson (2003) type ozone forcing.
- *Simulation Set C* examines stratosphere-troposphere dynamics in the presence of full dynamical coupling to the ocean circulation (AGCM coupled to ocean general circulation model).

We initially proposed that Simulation Set A be based on the CLIVAR Climate of the 20^{th} Century (C20C) prescriptions of forcings for SSTs, sea ice, and volcanoes (see SPARC Newsletter 29). We now modify this proposal in light of new integrations that the SPARC CCMVal group has committed to, in support of the upcoming SPARC CCMVal Report and the WMO/UNEP Ozone Assessment. The URL describing these integrations can be found on the CCMVal website: **http://www.pa.op.dlr.de/CCMVal/Forcings/CCMVal_Forcings_WMO2010.html**. We highlight CCMVal REF1 for the 1960-2006 period. The REF1 integrations include detailed



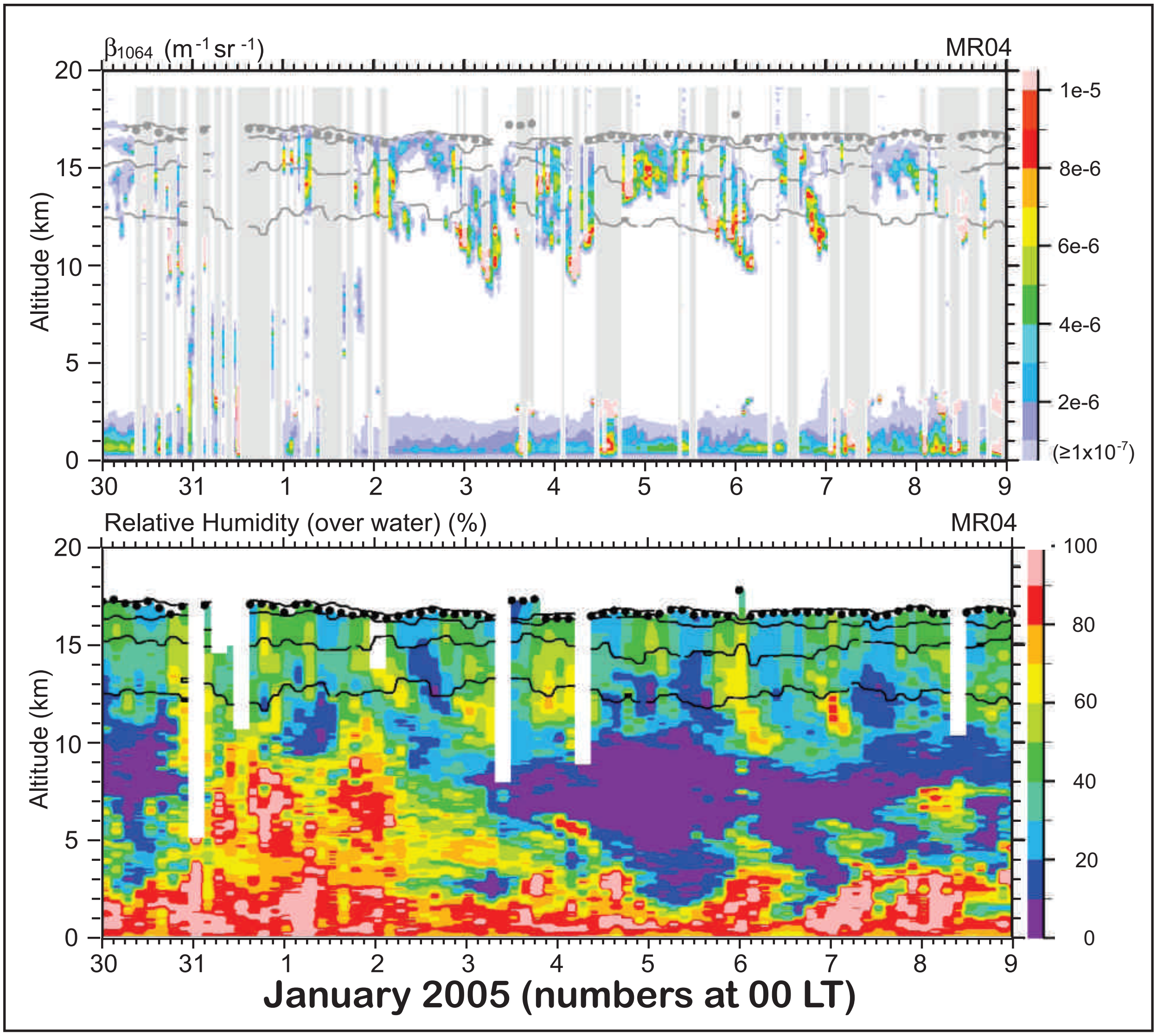
^ Figure 1

Ensemble-mean trends in zonal-mean force per unit mass due to resolved waves (m s^{-1} decade^{-1}) with the trends in vector EP flux (kg s^{-1} decade^{-1}) superimposed. From Garcia and Randel (2008).



^ Figure 2

Antarctic ozone in October (averaged poleward of 70°S) for four different simulations from the NASA/GSFC coupled chemistry climate model. The thick black line is an ozone simulation for the "world avoided", i.e. assuming there was no Montreal Protocol and CFCs increased 3 % per year. The future (past) reference simulation is shown in red (dark blue). A simulation with CFCs fixed at 1960 levels is shown in green. The latter curves are smoothed with a Gaussian filter with a half-amplitude response of 20 years, except for the "world avoided", which is unsmoothed. The inset false-color images show 1980, 2020, and 2060 with 20-DU colour increments (see inset scale) for the "world avoided" simulation. From Newman et al. (2008).



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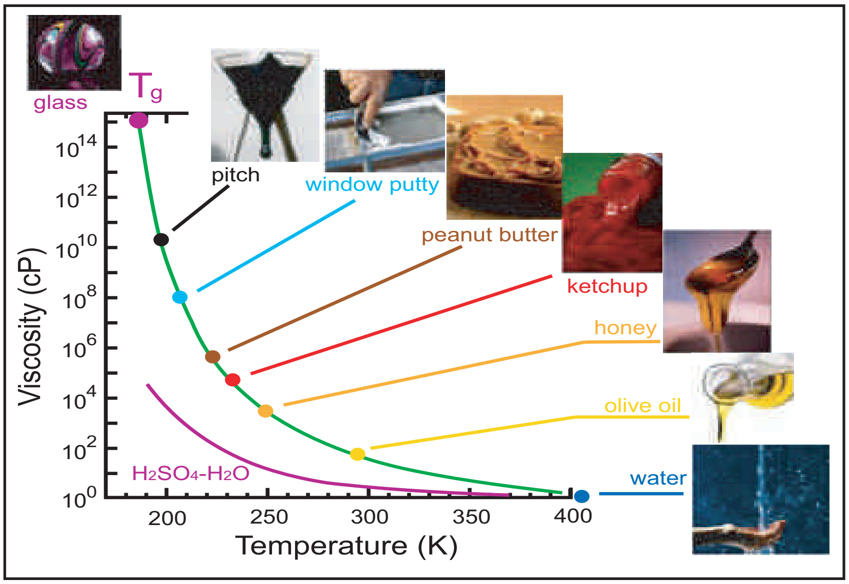
^ Figure 3

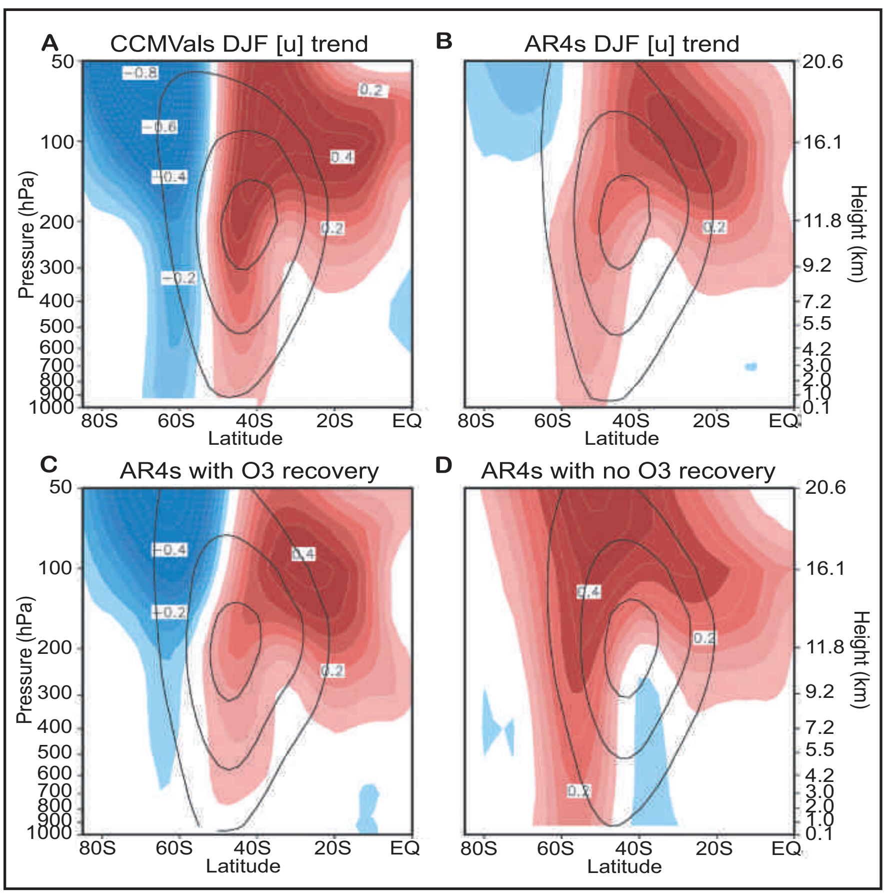
Diurnal variations in TTL cirrus. Upper panel: lidar backscatter coefficient, detecting cloud particles, showing sedimentation of particles from upper TTL in the evening to 10-12 km in the morning, almost every day. Lower panel: radiosonde relative humidity showing that clouds and high relative humidity are almost in phase. Adapted from Fujiwara et al. (2008).

Report on the 4th SPARC General Assembly



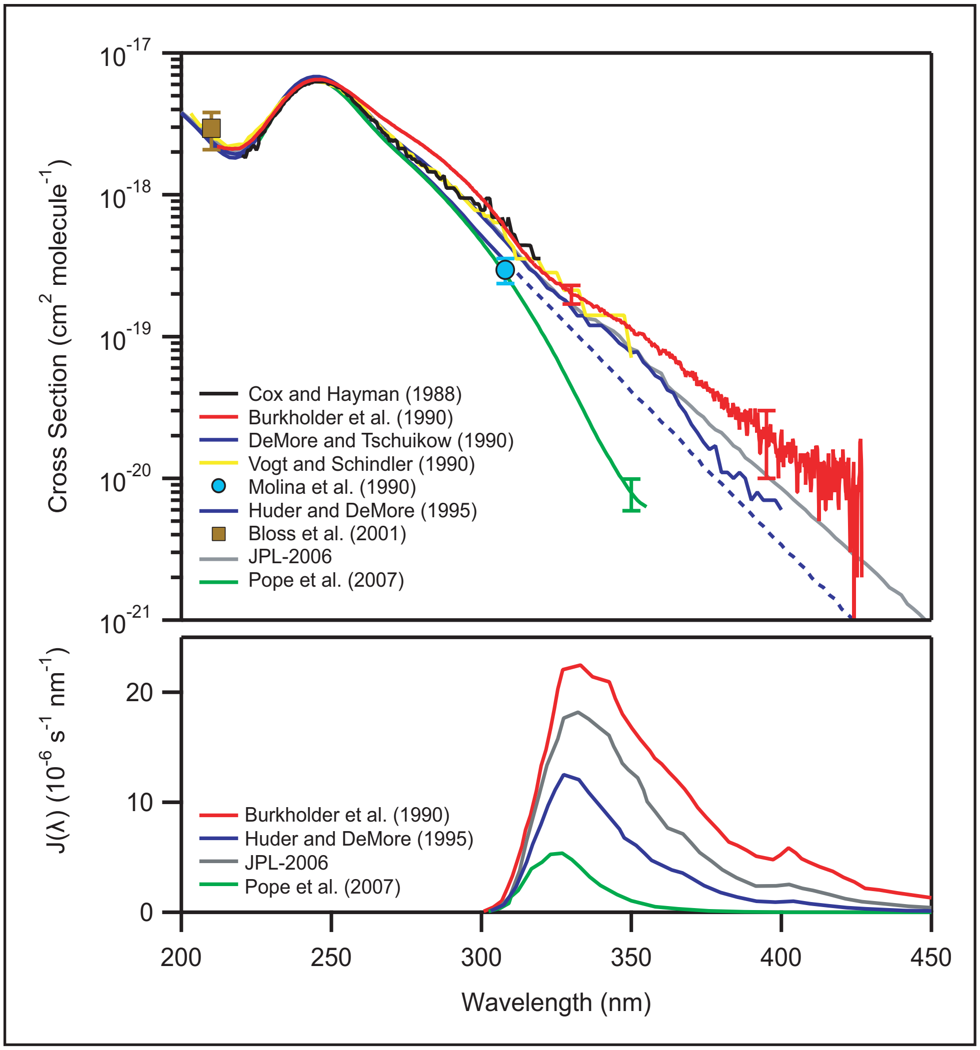
< Figure 4

Aerosols in the TTL contain 60-80% organics. In contrast to their inorganic counterparts (e.g. H_2SO_4-H_2O droplets), is it conceivable that these aerosols transform via more and more viscous states into glassy droplets under the extremely cold conditions in the TTL? And are these particles then incapable of taking up water and nucleating ice? Thought provoking questions asked by Koop et al. (2008).



< Figure 5

Trends in December-to-February (DJF) zonal-mean zonal wind. The multimodel mean trends between 2001 and 2050 are shown for the CCMVal models (A), the AR4 models (B), the AR4 models with prescribed ozone recovery (C), and the AR4 models with no ozone recovery (D). Shading and contour intervals are 0.05 ms^{-1} $decade^{-1}$. Deceleration and acceleration are indicated with blue and red colors, respectively, and trends weaker than 0.05 ms^{-1} $decade^{-1}$ are omitted. Superimposed black solid lines are DJF zonal-mean zonal wind averaged from 2001 to 2010, with a contour interval of 10 ms^{-1}, starting at 10 ms^{-1}. From Son et al. (2008). Reprinted with permission from AAAS.



^ Figure 1

The upper panel shows currently available ClO dimer absorption cross-section studies. The current NASA-JPL recommendation is also shown (grey line) while the IUPAC panel recommends the results from the Huder and DeMore study (blue line). The lower panel shows the wavelength dependence of the atmospheric photolysis rate constant at 20 km and a solar zenith angle of 86^o obtained using the ClO dimer cross-section values from Burkholder et al. (1990), Huder and DeMore (1995), NASA JPL-2006 and Pope et al. (2007). This shows the critical importance of the region between 310 and 400 nm and highlights the present level of uncertainty. (Figure courtesy of J. Burkholder, NOAA-ESRL. Lower panel adapted from Pope et al., 2007.)

prescriptions for various GHGs, a surface area density prescription for volcanic aerosols, solar irradiance inputs, and prescriptions for ozone depleting substances (ODS), all of which overlap significantly with the C20C prescription.

A key issue to be resolved prior to beginning these integrations regards the prescription of stratospheric ozone concentrations in REF1 type runs, since ozone will not be a predicted field in typical DynVar models. This has also been an issue for all the models in the CMIP3 project that contributed to the IPCC assessment reports, which used various prescriptions for ozone forcing. The lack of consistent stratospheric ozone forcing is an important source of discrepancy between the IPCC models' Southern Hemisphere tropospheric circulation response to climate change (see Miller *et al*., 2006, Perlwitz *et al*., 2008, Son *et al*., 2008). A SPARC working group, led by G. Bodeker, has been established to address the issue of deriving an authoritative observational ozone database for the period up to 2006. The results of this working group's activities are reported separately in this issue of the SPARC Newsletter.

The mixed layer Simulation Set B and the coupled ocean atmosphere Simulation Set C are not being carried out by any other SPARC project. The discussion on these two sets of simulations was started during the March 2008 workshop. However, given the computational demand of some of these simulations, we did not finish setting out the details of these simulation sets. We will briefly discuss coupled ocean-atmosphere modelling in the conclusion.

The DynVar Database and Data Distribution Policy

The principal activity of DynVar will be to analyse data from the DynVar model database. We aim to make it easy for modelling groups to provide data, and for all participants to use that data collaboratively. The DynVar database will be developed and situated at the University of Toronto. DynVar participants will sign (electronically) a data use policy, and then be granted access to the password protected database.

The database is served by a file server ("dynvar") with moderate data processing capabilities. This server has been purchased with the support of the Natural Sciences and Engineering Research Council of Canada. The server is a linux Network Attached Storage (NAS) RAID device that project participants will have accounts on. Roughly 3TB of backed up space will be available for the project, along with 1TB of scratch space; more will be added as needed and as financially feasible. Standard netcdf data processing tools (*e.g*. CDO, NCO) will be available so that participants can do some preliminary processing prior to downloading the data. Usage will be monitored to ensure that everyone has fair access to the machine.

Easy accessibility to the data needs to be balanced against other considerations. The DynVar model database will include model output from various international modelling groups and University groups, each with their own data sharing policies. Thus, we will need to be careful to conform to the needs of those groups, and to recognise the effort it takes to produce quality-controlled model output and to correctly interpret that model output. Fortunately, the CCMVal project has developed a two-phase data distribution policy that apparently satisfies the needs of the centres participating in that project. Thus, we propose to match our data policy to CCMVal's policy:

- A 1.5 year Phase 1 period during which participants are obliged to offer co-authorship on DynVar model-based research to model PIs, and
- A subsequent Phase 2 period during which the co-authorship obligation is lifted but during which DynVar participants are expected to communicate their results to model PIs to allow model PIs the possibility to comment on results. The latter is a best-practice policy that recognises the inherent difficulty in interpreting and intercomparing GCM results.

Model output will be provided from the DynVar database in the "CF compliant" netcdf format. This format conforms to that of several projects including CCMVal and CMIP3 (IPCC AR4). Because CF compliant netcdf format has become more common, many modelling centres will have routines to convert their native data into this format. However, the group at Toronto is prepared to convert surface and pressure-level data provided by the centres into the CF compliant format if required. The intention is to prevent data conversion from being a bottleneck in getting the data out to participants. Nevertheless, we will need all the modelling groups to be involved in quality control of the data.

We hope that the database will "stay live" and be updated on a regular basis, and that diagnostics developed by participants will be sufficiently straightforward that they can be repeated quickly as new data becomes available. Thus, if a modelling centre wishes to provide updated model data (*e.g.* extra realisations of a run or an updated model version) we will aim for a quick turnaround.

Several groups made informal commitments to provide data for the project. For more information, see the "survey synthesis" document on the project website.

Proposed Diagnostic Projects

A wealth of exciting research projects was outlined at the planning meeting in March, and these will be updated, summarised and put on the project website. It became clear that dynamical analyses of interest to DynVar participants require high-frequency — typically daily — sampling of meteorological fields, and serving this data will be a key goal for the project. In addition, we discussed the need for very high frequency output over relatively short periods to assist in the evaluation of GWD parameterization schemes against observations.

See the project website for an up-to-date list of projects submitted to DynVar. Many of the research projects within the CCMVal project will also be able to take advantage of the DynVar database. For more details, see the survey synthesis document on the project website.

Conclusion: Project Status & Looking Forward

After an exciting planning workshop in March, the project was significantly delayed by technical problems with P. Kushner's computer and storage hardware at the University of Toronto. These have been for the most part resolved and the dynvar server should be available by the end of 2008. Some preliminary integrations for the project have already been carried out, and the output from these integrations will be made available once the server is ready. These will serve as a starting point for more coordinated simulations in future.

At the recent SPARC Scientific Steering Group meeting (discussed in this newsletter), P. Kushner gave a progress report on the DynVar project. Some of the main points from that report and subsequent discussions follow:

- We proposed that the DynVar project would be one of the first users of the new ozone forcing database through Simulation Set A (REF1) and B (Mixed Layer) integrations.
- We recognised that the DynVar project will probably need to wait for the CCMVal runs to be completed before expecting major commitments from participating modelling groups to run simulations for and provide data to the project.
- We discussed coupled ocean atmosphere modelling with high-top models, a theme that is not the focus of any other SPARC project. This is an important aspect of the DynVar project because it will enable the stratospheric modelling community to test its models within the experimental design of the core simulations of the CMIP3 project and the new CMIP5 project, which provide the simulations for climate change assessment. We are therefore strongly encouraging several groups to carry out such simulations to examine stratospheric impacts on climate variability and sensitivity in the presence of realistic ocean coupling.
- We envisioned a future focus on tropical troposphere-stratosphere variability, with a view to an intercomparison of models that are capable of spontaneously simulating of the main features of the QBO. Outcomes from this expanded project would shed light on the meaning of "a good representation of the stratosphere," as well as on simulating important aspects of tropical tropospheric circulation.
- Finally, we proposed to hold a second DynVar workshop in Hamburg on April 27-28, 2009, during which these topics and early results will be discussed.

Details of future plans and the workshop will be posted on the DynVar project website.

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Report on the SPARC Workshop on the Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion

17-19 June 2008, Cambridge, UK

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on behalf of the Initiative Steering Group and Workshop Participants

Introduction

The scientific understanding of ozone loss in the Arctic and Antarctic stratosphere is built upon a combination of scientific discoveries and tested hypotheses extending from laboratory studies of reaction mechanisms, to *in situ* and remotely sensed atmospheric observations, global satellite observations and coordinated modelling analyses. The depth of this understanding has created a strong scientific link between the emissions of organic chlorine and bromine containing compounds *via* human activities, and the catalytic loss of ozone over polar regions in the late winter and spring of each year since the 1970s. The chain of tested hypotheses linking the reactions of specific radicals and molecules to the direct observation of stratospheric ozone loss has played an important role in the formulation of international policy *via* the Montreal Protocol and its subsequent Amendments and Adjustments. Recent laboratory results from Pope *et al*. (2007) have raised questions about one of the crucial steps in the chlorine-catalyzed loss of ozone in the polar stratosphere. They report a significantly smaller cross-section for the photodissociation of the chlorine monoxide (ClO) dimer, ClOOCl, than previously measured, which has challenged the quantitative analysis of ozone loss rates in the winter/spring Antarctic and Arctic lower stratosphere. To address these issues, a new SPARC initiative was installed in the fall of 2007 with the specific objectives to:

1. Evaluate consequences of the new laboratory data for the ClO dimer photolysis rate on simulations of stratospheric ozone depletion, particular in winter polar regions.
2. Evaluate old and new laboratory results for the photolysis rate and the type of further studies that are necessary to resolve current differences.
3. Assess qualitative and quantitative evidence from the laboratory, field obser-

vations, and models linking polar ozone depletion to stratospheric active chlorine and bromine amounts.

An important step in addressing the initiative objectives was the organisation of a workshop bringing together expertise from the laboratory, theory, atmospheric observations and atmospheric modelling communities. The workshop was held in Cambridge, UK, during 17 – 19 June 2008 with more than 50 participants.

Laboratory Studies and Theoretical Calculations

Differences in the ClOOCl absorption cross-section data at wavelengths longer than 300 nm from various laboratory studies have existed before 2007 (Sander *et al*., 2006; WMO, 2007), and, in fact, provided the motivation for the recent Pope *et al*. (2007) study of the ClOOCl spectrum. These researchers developed a new method to prepare bulk ClOOCl samples that reduced the abundance of several Cl_xO_y impurities that were present in several of the previous studies. However, significant Cl_2 impurities were still present in their gas-phase samples. They employed a new spectral analysis approach to correct for the Cl_2 impurity and subsequently obtained ClOOCl UV absorption cross-sections significantly lower than all previous measurements. **Figure 1** (colour plate IV) shows the ClOOCl absorption spectra and cross-section values reported in published studies, as well as the NASA-JPL 2006 (Sander *et al*., 2006) recommended values. Figure 1 also shows the wavelength dependence of the atmospheric photolysis rate at 20 km and a solar zenith angle of 86^o obtained using the ClO dimer cross-section values from Burkholder *et al*. (1990), Huder and DeMore (1995), NASA JPL-2006 and Pope *et al*. (2007). Two points are readily apparent from the figure. First, the disagreement in the published cross-sections is indeed large – a factor of ~4.5 at 330nm, 14 at 350nm and 100 at 380 nm. Second, the most important region for atmospheric photolysis is 310-400 nm, so the disagreement in ClOOCl cross-section is large where it is atmospherically most important. It is worth noting that the agreement at the absorption maximum at 245 nm (±15%) is based on four absolute measurements (Cox and Hayman, 1988; Burkholder, 1990; DeMore and Tschuikow-Roux, 1990; Bloss *et al.*, 2001). Other studies make relative measurements, which are normalised to the peak value. So why are the uncertainties in a critical atmospheric parameter so large? Historically, there have been four reasons:

(a) It is very difficult to prepare pure ClOOCl in the laboratory;
(b) Its UV absorption spectrum is relatively smooth, with no significant unique features;
(c) There are a number of potential interferences from other Cl_xO_y species (*e.g*. Cl_2 and Cl_2O_3) whose presence in laboratory studies is almost unavoidable and hard to quantify;
(d) The cross-sections in the region of atmospheric interest are small.

The biggest source of uncertainty in spectroscopic studies (including Pope *et al*. (2007)) is now thought to arise from the presence of Cl_2, since the derived spectrum is very sensitive to how the Cl_2 interference is removed. Assuming relatively small differences in the amount of Cl_2 yields results that span the range from the highest to the lowest published absorption cross-sections, thereby pointing to the need for very accurate quantification of the Cl_2 present in the system when the absorption cross-section is determined. Absorption due to Cl_2 was assumed to make a significant contribution to the absorbance signal measured by Pope *et al*. (2007), and the dimer cross-sections reported were derived by subtracting this contribution. A further problem is that not all the properties of the other Cl_xO_y species are known. For example, the significant disagreement among the published values of the Cl_2O_3 spectra leads to considerable uncertainty in accounting for its possible presence and impact on the derived ClOOCl absorption cross-sections, especially in the region between 300 and 340 nm.

New laboratory studies currently being carried out in four different institutes were reported at the workshop. They are based on independent experimental approaches: pulsed laser photolysis combined with diode array absorption spectroscopy (NOAA Earth System Research Laboratory, Boulder, US), IR and UV spectroscopy on matrix isolated ClOOCl (Forschungszentrum Juelich/University of Wuppertal, Germany), monitoring Cl production from ClOOCl laser photolysis by resonance fluorescence (Harvard University, USA), and repeating the Pope *et al*. (2007) experiment with simultaneous monitoring of the Cl_2 concentration by cavity enhanced absorption spectroscopy (University of Cambridge, UK). More details on these highly complementary experiments can be found in the full workshop report, which will be available on the SPARC website.

New calculations (**D. Dixon** and co-workers) of the energetics, structures and spectroscopic properties of various isomers of Cl_2O_2 are being carried out with the latest Molecular Orbital Theory approaches. In contrast to some earlier studies, $ClClO_2$ is found to be thermodynamically the most stable isomer, 3.1 kcal/mol more so than ClOOCl. The weakest bond in $ClClO_2$ is calculated to be the Cl-Cl bond, while in ClOOCl it is calculated to be the O-O bond. Further analysis and calculation are needed to produce the potential energy surfaces for the Cl_2O_2 system, and to provide insight into the kinetic barriers to formation and dissociation. The presence of any low-lying excited states will be important in this regard and their calculation might be challenging in this electron-rich system. New information about the electronic transitions and possible absorption features is also becoming available. This information can serve as a guide in examining the role of various species in the search for missing chemistry.

Atmospheric Observations

Chlorine Partitioning

The workshop featured numerous presentations on observations of [ClO], [ClOOCl] and related species, and associated modelling analyses used to place constraints on the photodissociation frequency of ClOOCl. These talks either updated the literature by repeating model/measurement comparisons using the Pope *et al*. (2007) cross-section, or highlighted new model/measurement comparisons that shed light on the impact of the lower cross-sections on our understanding of polar ozone photochemistry.

Stimpfle *et al.* (2004) used the ratio of modelled $[ClO]^2/[ClOOCl]$ to the measured value of this quantity as an indicator of the level of agreement between models (using different photochemical parameters that govern the partitioning of ClO and ClOOCl) and measurements. **Figure 2** shows an update to these β ratio plots including an analysis using the Pope *et al*. (2007) value of the ClOOCl cross-section.

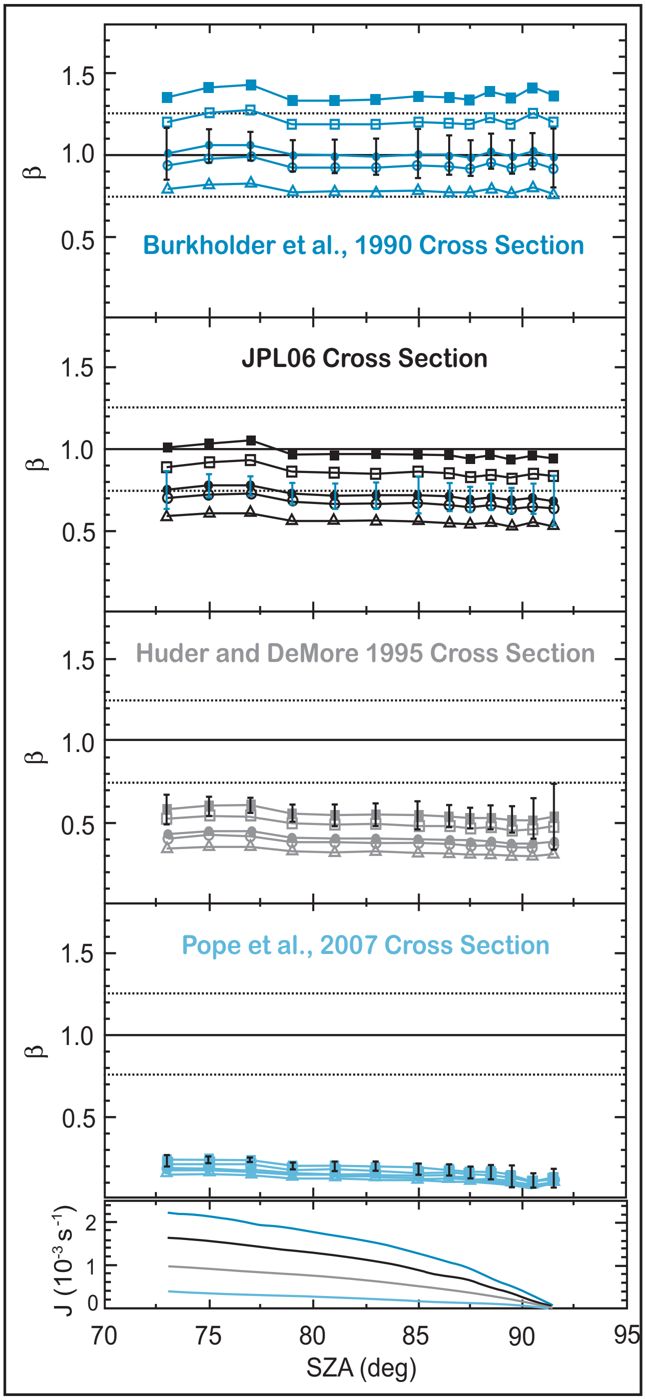

Figure 2: Analysis of daytime measurements of [ClO] and [ClOOCl] obtained during the SAGE III Ozone Loss and Validation Experiment (SOLVE). Values of β (see text) are shown as a function of solar zenith angle (SZA). Each panel represents model results for a different value of the ClOOCl absorption cross-section, as indicated. The five lines on the top four panels show results for five values of k(ClO+ClO+M): Troiler et al. (1990), JPL 2006, Bloss et al. (2002), JPL 2002 (Sander et al., 2003), and Boakes et al. (2005). The bottom panel shows the SZA dependence of J(ClOOCl), for the four values of σ_{ClOOCl} used in the analysis. Error bars on the model results depict the standard deviation about the mean of the individual data points that fall within the various SZA bins. The dotted horizontal lines depict the ±25% uncertainty in β attributable to uncertainties in the observations of ClO and ClOOCl. After Stimpfle et al. (2004) and Figure 4-15 of WMO (2007). Figure courtesy T. Canty and R. Salawitch, University of Maryland.

The analyses shown at the workshop indicated that models and measurements of the $[ClO]^2$ /[ClOOCl] ratio are completely inconsistent if the Pope *et al.* (2007) cross-section is used to compute J(ClOOCl) and no other kinetics changes (or processes) are invoked.

Detailed discussion at the workshop focused on the uncertainties of the field measurements of [ClO] and related species and concluded that the inconsistency between measurements and models using the Pope *et al*. (2007) cross-section is robust even in light of these uncertainties. Presentations also examined the sensitivity of calculated [ClO] to various kinetic parameters with the consistent conclusion that measured and modelled ClO could not be reconciled using the Pope *et al.* (2007) cross-section without invoking some unknown additional chemical process that converts ClOOCl to ClO.

Diagnosed Ozone Loss

The ultimate test of our understanding of halogen-driven ozone loss chemistry is the simulation of the details of observed ozone change in polar regions. This can be a difficult diagnostic because it also depends on non-halogen chemical processes and transport, which cannot always be well constrained. A number of different techniques and diagnostics, based on satellite observations of the MLS, POAM and ODIN-SMR instruments and ozone sondes were presented.

Santee *et al*. (2008) found that ozone loss observed by ACE and MLS in a number of Arctic and Antarctic winters is significantly underestimated by model runs employing standard chemistry and J(ClOOCl_Pope). Von Hobe *et al.* (2007) could only reproduce half the ozone depletion observed at the end of a typical Antarctic winter in simulations using J(ClOOCl_Pope) (see Figure 11 in von Hobe *et al*. 2007). A comparison of modelled ozone loss rates and those observed by coordinated ozone sonde observations ("Match technique") leads to similar conclusions. To explain observed loss rates during a number of cold Arctic Januarys, a contribution to stratospheric bromine from very short-lived species (VSLS) and J(ClOOCl) at the upper end of available laboratory measurements have to be assumed (Frieler *et al*., 2006). The cold Arctic winter 1999/2000 provides a key test of our quantitative understanding of the observed ozone loss rates, since *in situ* measurements of ClO and ClOOCl are available from the SOLVE campaign at the same time as ozone loss rate measurements were being made. **Figure 3** compares ClO_x observations with modelled amounts (using different ClOOCl cross-sections) when the model attempts to match measured ozone loss rates. This comparison illustrates that the ClO_x thus required in a model based on standard chemistry (and high bromine) best agrees with observations if J(ClOOCl_Burkholder) is used. ClO_x calculated using J(ClOOCl_JPL06) agrees with observed ClO_x within the combined uncertainties of the ClO_x and ozone loss observations, while the agreement between the measured and modelled ClO_x based on J(ClOOCl_Huder&DeMore) is marginal. ClO_x required to match the ozone loss rates in a model using J(ClOOCl_Pope) together with the highest estimates for stratospheric bromine cannot be reconciled with observations.

Missing Chemistry

Atmospheric observations clearly indicate that if the value of J(ClOOCl) based on the Pope *et al*., cross-sections is correct, then an unknown process must titrate chlorine from ClOOCl back to ClO during daytime in a manner that mimics J from either the JPL 2006 or Burkholder *et al*. (1990) cross-sections. Otherwise the calculated ClOOCl abundance is much larger than actually observed, and the calculated ClO concentrations and ozone loss rates are much lower than measured. Hence, if J(ClOOCl) is

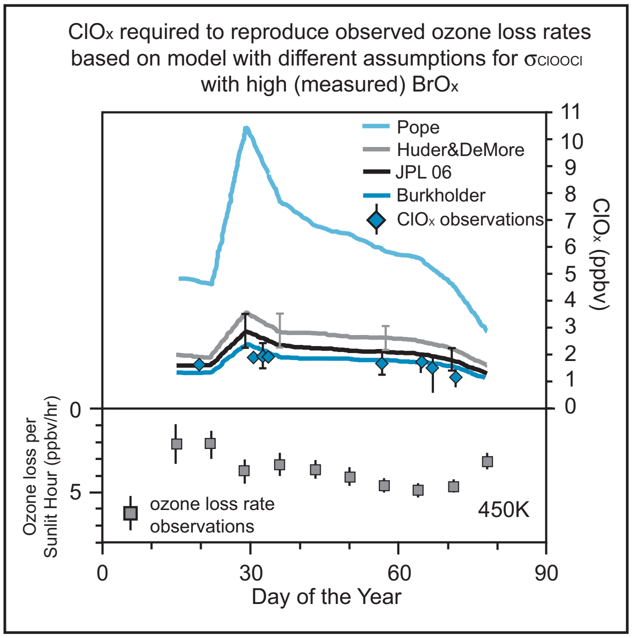

Figure 3: Ozone loss rates and reactive chlorine abundance at the 450 K surface for Arctic winter 1999/2000, as a function of day of year in 2000. The chemical O_3 loss rate is based on the Match analysis of ozone sonde data (grey boxes; error bars are 1σ uncertainty). The lines represent the necessary ClO_x to account for the measured O_3 loss, where the line colour indicates the source of the absorption cross-section for ClOOCl used in the simulation. All model runs used BrO_x calculated from measured BrO, which results in a significantly higher stratospheric bromine loading than can be accounted for by CH_3Br and halons. Blue diamonds show the mean value of ClO_x measured at 450±10 K, inside the vortex, for eight ER-2 flights during SOLVE/THESEO 2000; vertical bars represent the maximum and minimum value of ClO_x observed for each flight on this potential temperature surface. After Frieler et al., (2006) and Figure 4-17 of WMO (2007). Figure courtesy R. Schofield and M. Rex.

close to J(ClOOCl_Pope), there must be a mechanism that prevents the buildup of ClOOCl by either limiting the loss of ClO to the dimer or by rapidly converting ClOOCl back to ClO. In principle, to prevent the buildup of unrealistic amounts of ClOOCl, either the production rate of ClOOCl could be slower than in the standard chemistry or a currently unknown additional breakdown mechanism could exist.

A ClOOCl production rate slow enough for the observations to be consistent with J(ClOOCl_Pope) appears to be ruled out by extensive lab studies. This focuses attention to possible alternative breakdown mechanisms for ClOOCl. Such mechanisms fall into two basic categories: (1) Cl atoms are directly recycled by the breakdown of ClOOCl without requiring a photolytic step, and (2) another night-time reservoir is formed by a reaction involving ClOOCl.

In order to match observations, a category (1) process would require reaction with a species whose concentration varies with solar zenith angle in a manner corresponding to J(ClOOCl_Burkholder) or J(ClOOCl_JPL2006). Essentially all possible reactions can either be ruled out by laboratory studies, the atmospheric concentration of the possible reactive species necessary to have an appreciable effect, or the incompatibility of possible products with observed ClO abundances.

Invoking the transformation of ClOOCl into another reservoir requires that the new reservoir photolyse in a manner mimicking J(ClOOCl_Burkholder) while producing a species that preserves or reforms the O-O bond. Matching the observed concentrations of ClO and ClOOCl and the observed ozone loss rates places additional constraints on such new chemistry. Various possibilities were examined and discussed at the workshop and are summarised in greater detail in the full workshop report.

The search for missing chemistry has not been successful given the significant number of observational constraints. Hence, it presently is very difficult to reconcile a value for the ClO dimer photodissociation rate much slower than current recommendations.

Modelling

Calculations of polar ozone loss with 3D models depend on many more parameters than the dimer photolysis. In order for a 3D model to simulate realistic polar ozone loss it needs to reproduce many processes including: (i) transport and degradation of chlorine source gases through the stratosphere; (ii) polar meteorology *(i.e.* polar vortex and temperatures); (iii) activation of chlorine species on polar stratospheric clouds; (iv) polar denitrification/dehydration processes and (v) deactivation. For these reasons, comparison of 3D model ozone loss with observations is not a

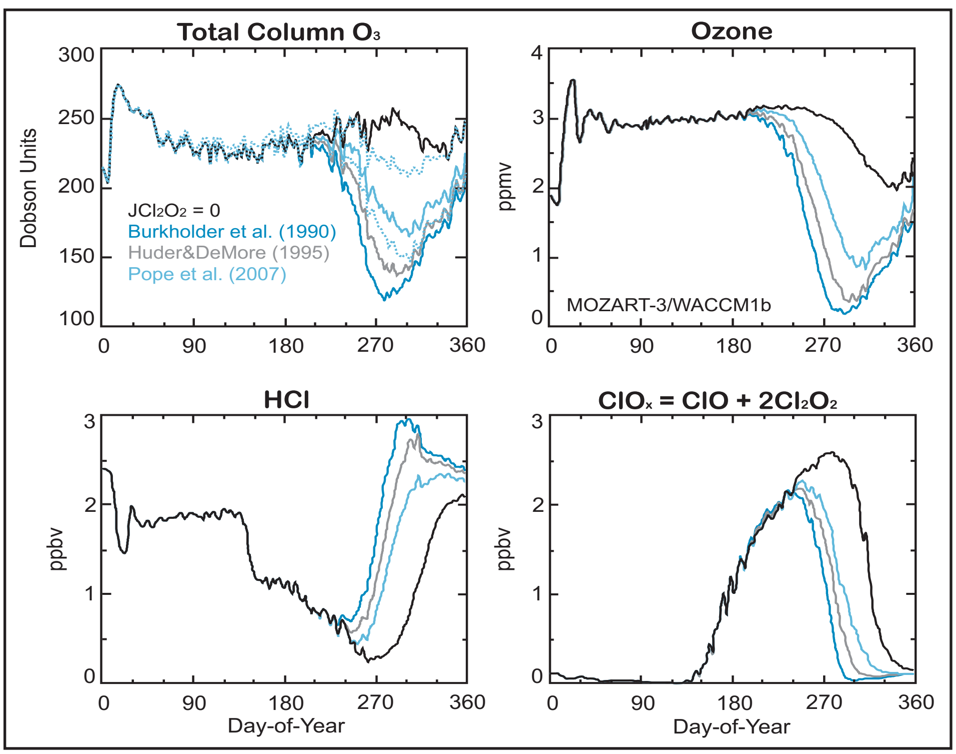

Figure 4: The zonal-mean annual cycle at 82°S is shown for select species from the MOZART-3 CTM driven with WACCM meteorological fields assuming different ClO dimer cross-sections and total inorganic bromine abundances (0, 16, 22 pptv). Panel (a) shows the evolution of total column ozone. For the Pope et al. (2007) simulation (light blue line), the sensitivity of total inorganic bromine (Br_y) is also shown (dotted lines). The case with zero Br_y shows only a small decrease in total column ozone during Antarctic spring conditions. The case with 22 pptv has approximately 20% more column ozone depletion relative to the reference case (16 pptv Br_y). Panels (b)-(d) show the volume mixing ratio evolution at 82°S, 43 hPa for O_3, HCl, and ClO_x.

critical test of a single photochemical parameter. However, given the large impact of the Pope *et al*. (2007) cross-sections on ClO_x partitioning it is useful to explore the impact on 3D model runs.

Three-dimensional models can be categorised as either 'off-line' chemical transport models (CTMs) or coupled chemistry-climate models (CCMs). CTMs are forced by analysed winds and temperatures, and thus are constrained by 'real' meteorology. They will therefore have realistic polar temperatures but can still be subject to transport problems with the analysed winds. CCMs calculate their own winds and temperatures, and are needed for predictions of the future. At the Workshop, a range of 3-D CTM results (SLIMCAT, CLaMS, KASIMA) was presented for recent Arctic and Antarctic winters. Using ECMWF meteorology, they all showed significantly less modelled ozone loss (*e.g*. 30-50% less column depletion) and poorer agreement with observations using the Pope *et al*. (2007) cross-sections compared with the Burkholder *et al.* (1990) values.

Figure 4 shows example 3-D model results for the Antarctic using the MOZART-3 chemical-transport model (Kinnison *et al*., 2007) driven with winds from the chemistry-climate model WACCM. This approach decouples the feedback between chemistry and dynamics and allows a straightforward comparison of chemical sensitivity for a given choice of the ClO dimer cross-section. Overall MOZART-3 was run 4 times with different assumptions for the ClO dimer absorption cross-sections. As a sensitivity test, the Pope *et al*. (2007) ClO dimer cross-section case was simulated with three different choices for total inorganic bromine (0, 16, and 22 pptv). In addition, one simulation assumed that the ClO dimmer photolysis rate is zero. In Figure 4, column ozone evolution, along with local ozone, HCl, and ClO_x (ClO+2ClOOCl) are shown. As ClO dimer photolysis becomes slower (ranging from Burkholder *et al*. (1990) to J(ClOOCl)=0), the partitioning of ClO_x into ClOOCl increases, the deactivation of ClO_x and recovery of HCl is delayed, and the O_3 loss rate decreases. While the simulation with Pope *et al*. (2007) cross-sections and high bromine still shows an "ozone hole", it is not as deep as observed, consistent with the other CTM results mentioned above.

Outlook

A comprehensive Workshop Report containing more detailed information in each of the areas (laboratory measurements, observations, and modelling) will be available electronically through the SPARC web site. In addition, a list of topics in each of these areas is being assembled through this SPARC initiative in an effort to promote collaborative studies leading to publications in a special journal issue. The timing of these publications will aim for availability by authors of pertinent chapters in the forthcoming 2010 WMO/UNEP Scientific Assessment of Ozone Depletion.

Acknowledgements

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Report on SPARC Ozone Recovery Workshop

8-9 May 2008, Boulder, USA

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Introduction

The definitions of ozone recovery used in the 2006 WMO/UNEP Scientific Assessment of Ozone Depletion, while self-consistent, did not satisfy the full spectrum of needs of the ozone- and UV-research communities. As a result there was a strong desire to develop an improved and revised framework for the discussion of ozone recovery in preparation for the next WMO/UNEP ozone assessment. To this end a SPARC workshop on ozone recovery was convened in Boulder on 8 and 9 May 2008.

The issue

Chapter 6 of the 2006 WMO/UNEP ozone assessment defined three stages of ozone recovery, *viz.*:

i) The slowing of ozone decline, identified as the occurrence of a statistically significant reduction in the rate of decline in ozone due to changing equivalent effective stratospheric chlorine (EESC).
ii) The onset of ozone increases (turnaround), identified as the occurrence of statistically significant increases in ozone above previous minimum values due to declining EESC.
iii) The full recovery of ozone from ozone depleting substances (ODSs), identified as when ozone is no longer significantly affected by ODSs. In the absence of changes in the sensitivity of ozone to ODSs, this is likely to occur when EESC returns to pre-1980 levels.

To clarify exactly what was meant by 'full recovery' of ozone, it was stated "This third stage may or may not be accompanied by the actual return of ozone to pre-1980 levels, and it is possible that ozone could return to 1980 levels before the effects of ODSs disappear". However, in an effort to provide an complementary approach, it was also stated that "In reaching full recovery of ozone, the milestone of the return of ozone to pre-1980 levels is considered important because ozone was not significantly affected by ODSs prior to 1980".

Two different approaches were considered when defining these stages of ozone recovery:

1) *Unattributed recovery*: When ozone goes up, ozone is recovering, and when ozone exceeds a specified value (*e.g.* 1980 values) then ozone has recovered.
2) *Attributed recovery*: When ozone goes up in response to changes in ODSs, then ozone is recovering.

The definitions used in the ozone assessment were in the context of attributed recovery.

The advantage of unattributed recovery is that it is easy to apply – one need only consider ozone time series to detect various stages during the recovery. Furthermore, it is the most relevant approach for the 'effects' community. Ozone recovery means UV recovery. However, if ozone increases due to non-ODS causes (*e.g.* changes in dynamics), then one would conclude that ozone is recovering or that ozone has recovered, but ODSs could still be playing a major role. In addition, if the non-ODS cause reverses, what would be concluded: Ozone was recovering and now it isn't? Other disadvantages of the unattributed approach are that ozone may never recover if non-ODS causes result in continued declines (*e.g.* in the tropical lower stratosphere), and the occurrence of full recovery is sensitive to the 'baseline' (*e.g.* 1980 or 1960 values).

The advantage of the attributed approach is that if factors other than ODSs affect ozone it doesn't matter; it is only the response of ozone to ODSs that matters. Furthermore, ozone recovery doesn't depend on climate change (unless one considers climate change induced changes to the Brewer-Dobson circulation which may affect the conversion of CCl_y to Cl_y), and one need not consider the so-called 'super recovery' of ozone. That said, the attributed approach is more obscure and more difficult to calculate since non-ODS drivers of ozone changes must first be removed. This definition also has less relevance for the UV effects community.

The focus of the SPARC workshop was to consider whether there was some way we could move beyond this binary, mutually exclusive, choice of attributed or unattributed recovery.

Presentations

The workshop was attended by 16 people and a number of presentations were made to address key questions related to the ozone recovery issue. Rather than having 16 different views presented on how ozone recovery should be defined, attendees were asked to focus on specific issues in ozone recovery, and to present all sides of the debate in those presentations. **M. McFarland** and **A. R. Ravishankara** discussed what might be the appropriate framework for the ozone recovery process and whether this framework would need to be different to meet the needs of scientists and policymakers. They also considered who might be other 'clients' for analyses of ozone recovery. **J. Daniel** considered whether ozone recovery should be defined only in terms of ozone, in terms of changes relative to halogens, or in a different manner, and specifically what should be the role of attribution in analyses of ozone recovery.

E. Weatherhead discussed the pros and cons of examining ozone at fixed times (*e.g.* what will ozone look like in 2050 or 2080) rather than the date of occurrence of some event (see **Figure 1**). Two questions that are likely to be of interest are: (1) how much of the ground lost by ozone to ODSs has been regained (a/b in Figure 1) and (2) how much of the ground regained is due to ODSs and how much is due to other factors, *e.g.* climate change? E. Weatherhead also discussed whether the stages and milestones of recovery apply to other parameters/observables, in particular to EESC and UV.

D. Fahey presented a discussion of the key stages in the recovery process and to what extent these stages can be identified *via* observations. This included an assessment of the best parameters/milestones to define the recovery processes and whether the occurrence of these milestones can be quantified with current or future observation systems. **D. Cunnold** considered whether the defined stages of ozone recovery apply to all regions of the atmosphere and for ozone mixing ratio as well as total column ozone. **P. Newman** and **D. Kinnison** considered how well we might predict the occurrence of milestones, and in particular the occurrence of full recovery of the ozone layer and whether models were sufficient to this task. **M. Rex** and **R. Müller** examined how climate change might modify the recovery process and the stages and timing of ozone recovery. This included a presentation on how geoengineering, in the form of addition of sulphate to the stratosphere, might affect the global recovery of ozone.

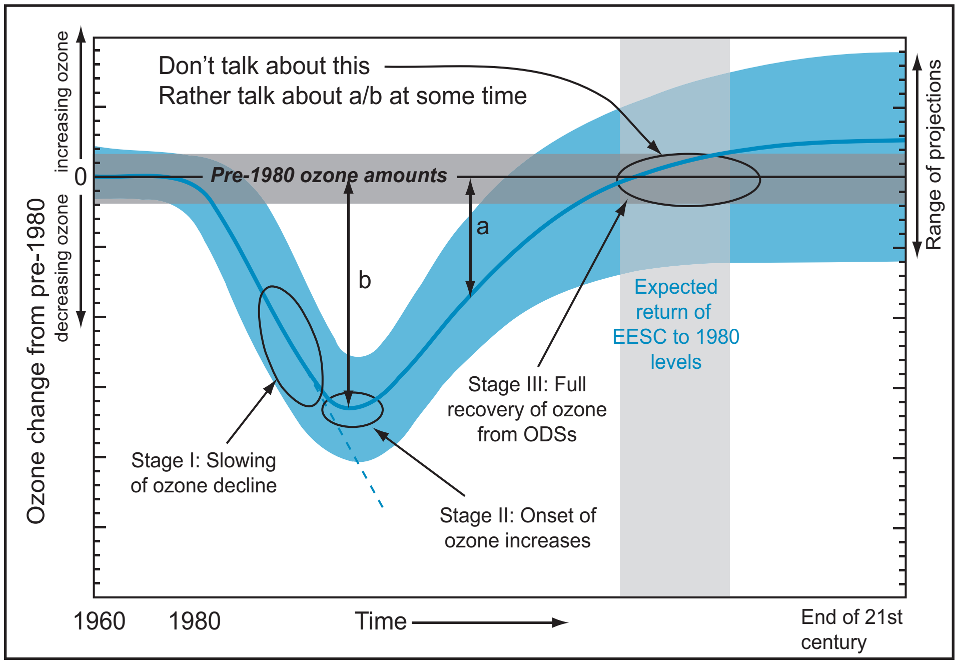

Figure 1: Considering ozone at fixed times in addition to the 3 traditional stages of ozone recovery.

Key results

The key results from these presentations included:

- Ozone recovery to pre-1980 values will almost certainly not occur simultaneously with ODSs reaching pre-1980 values.
- In current analyses of ozone recovery, including the analyses presented in the 2006 WMO/UNEP ozone assessment, the uncertainty in past and future EESC is underestimated. Future EESC depends on more than just the ODS emission scenario. The return of EESC to 1980 levels is sensitive to fractional chlorine release values and there is a need to consider changes in the lifetimes of ODSs and transport pathways through the stratosphere. Future changes in EESC are sensitive to the age spectrum and so if models are to accurately capture future changes in EESC, their representation of stratospheric dynamics must be sufficient to capture the age spectrum.
- By prescribing ODS concentrations rather than ODS emissions, CCMs hide much of the variability that would result in modelled EESC.
- Ozone depletion started before 1980 and using 1980 as the baseline will exaggerate 'super recovery'.
- A more careful assessment of data quality with regard to detection of ozone recovery in all parts of the atmosphere might be necessary – the noise on the signal is not just natural variability.
- Continued satellite and aircraft observations of Br_y and Cl_y species are necessary for model evaluation of ozone recovery processes.
- A key question that was raised during the discussion was "Would the Montreal Protocol be considered successful if ozone never returned to pre-1980 levels, but ODSs did?"

A proposed new framework

The presentations generated considerable discussion which led to one suggestion of a possible new framework for discussing and analysing ozone recovery (see **Figure 2**). The structure of the new framework is driven by two key questions, *viz.*:

a. Has the Montreal Protocol been successful?

b. What will happen in the future?

The first question is retrospective, analysing changes in a number of metrics to date to gauge the success of the Montreal Protocol. The second is prospective, making use of a range of tools to project future changes in those same metrics. The metrics

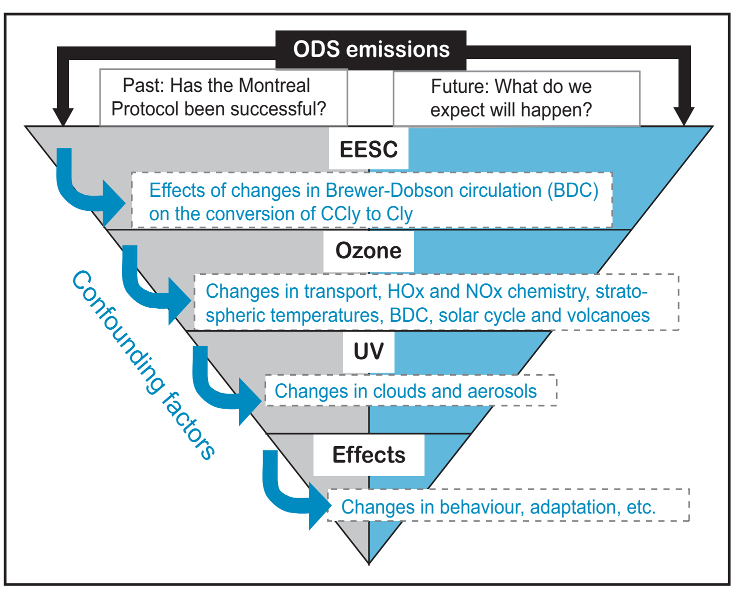

Figure 2: A schematic representation of the new framework for a discussion of ozone recovery. Metrics towards the top (EESC and ozone) can be more directly linked to ODSs and are therefore more applicable to answering the question of whether or not the Montreal Protocol has been successful. However, metrics towards the bottom (UV and effects of excess UV) are more relevant to the ultimate goals of the Protocol; were it not for the adverse affects of excess UV, the Montreal Protocol would be far less relevant. The factors confounding the links between lower level metrics and higher level metrics are shown. The inverted pyramid captures the reduction in certainty with which the two questions posed at the top can be answered.

proposed here span the causal chain linking emissions of ODSs through to the adverse effects of enhanced UV radiation, *viz.*:

1) Equivalent effective stratospheric chlorine.
2) Stratospheric ozone.
3) Surface UV radiation.
4) Effects of enhanced UV radiation on the biosphere.

Both for the past and for the future, ODS emissions are the primary focus. However, each link in the causal chain of emissions→EESC→ozone→UV→effects introduces a number of non-ODS influences, which contribute to variability and confound the use of that metric in assessing the effectiveness of the Montreal Protocol. These same influences make projections of these metrics less certain.

♦

Report on SPARC Ozone Database Workshop

30-31 August, Bologna, Italy

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Introduction

Trends in stratospheric ozone are known to drive trends in surface climate, and therefore including secular ozone changes in global climate model (GCM) simulations is vital to projecting future climate in a comprehensive manner. As stated in Chapter 10 of the IPCC 4th Assessment Report (AR4) *Climate Change 2007: The Physical Science Basis*, 'The inclusion, magnitude and temporal evolution of the remaining forcing agents...were left to the discretion of the individual modelling groups. These agents include tropospheric and stratospheric ozone...'. As a result, the GCM simulations for AR4 used a variety of ozone boundary conditions. For simulations during the period when ozone measurements are available, some models used Randel and Wu (1999), some used Kiehl *et al*. (1999), some used Harris *et al*. (1998), and others excluded ozone radiative forcing completely. Similarly, for simulations of future climate change, some GCMs incorporated ozone layer recovery, some kept ozone constant, and others excluded ozone radiative forcing altogether. This was not very satisfactory since those models that did not include ozone depletion and/or its recovery had limitations compared to those that did, *e.g*. there is a clear discrepancy in future changes in the Southern Annular Mode (see Figure 10 of Miller *et al*., 2006). To address this issue a SPARC workshop on ozone databases was convened in Bologna on 30 and 31 August 2008. The workshop was attended by 22 people.

The primary goal of the workshop was to discuss the creation of a new consensus, observational ozone database that can provide ozone boundary conditions for GCMs and Earth System Models (ESMs) that do not have interactive chemistry and do not generate their own ozone fields. For those models that do generate their own ozone fields, this database would be useful for validating the simulated ozone fields within those models. The database will be tailored for the CMIP5 community that will provide the model simulations in support of the IPCC 5th Assessment Report (AR5) and, once completed, will be made available to the community *via* the SPARC Data Center. **V. Eyring** presented the planned ozone database at a meeting of the Working Group on Coupled Modelling (WGCM) in Hamburg from 3 to 5 September 2008.

It was recognised at the SPARC workshop that uptake of this ozone database by the international modelling community, and in particular by CMIP5, would be more likely if:

- It is a consensus database. Expecting modelling groups to select from a menu of available observational ozone databases is unlikely to lead to convergence.
- It is published in the international peer reviewed literature – in particular that the methodology for the construction of the database is published.
- It has the *imprimatur* of an authoritative organisation such as SPARC.
- It is freely and easily available in a variety of formats that will meet the needs of the modelling community.

These requirements guided the discussions that took place during the workshop.

Database characteristics

The goal of the workshop was to discuss the creation of a new consensus observational ozone database, or a suite of databases, that will meet the needs of the GCM community, *viz.*:

- Vertically resolved at high resolution extending from the surface to the mesosphere (*e.g*. surface to 70 km at 1 km resolution)
- Pole-to-pole zonal means (*e.g*. 5° latitude zones)
- Monthly means spanning the full period of the planned GCM simulations (*e.g*. 1850 to 2150)
- No missing data
- Different styles of database that include, for example, just long-term secular trends (mean annual cycle + effects of halogens + linear trend), only natural variability (solar + QBO + volcanoes), natural + anthropogenic, *etc.*

Source observational data

Five different ozone databases were considered for use in this activity, *viz.*:

1) The NCAR database from Randel and Wu (Randel and Wu, 2007).

2) The NIWA database from Hassler and Bodeker (Hassler *et al*., 2008).
3) The NOAA database from Rosenlof and Gray.
4) The GSFC database from Stolarski and Frith.
5) The Environment Canada database from Fioletov and McLinden.

Presentations on the salient features of each of these databases were made at the workshop. Each of these databases has its advantages and disadvantages, and monthly mean times series from all but the GSFC database had been provided to NOAA before the workshop. **R. Portmann** presented a synopsis of the key differences between the four databases available. In spite of all of the databases being based on ozone observations, clear differences were apparent, resulting from selection of different satellite and ozonesonde source data, data smoothing, and screening of the source data. An ongoing iterative inter-comparison of all five databases is now underway with the goal of converging on a consensus database.

Issues and their resolution

A number of issues were identified and discussed at the workshop:

Data gaps: Whatever source measurement sets are used, it is almost certain that they will not provide the complete geographical coverage required. As a result, spatial and/or temporal interpolation is required to fill the gaps. It was decided that each participating group would be responsible for developing and applying their own gap filling algorithms.

Capturing key ozone depletion regions: Studies have shown that the changes in radiative forcing resulting from polar ozone depletion, and in particular Antarctic ozone depletion, are very important (Keeley *et al*., 2007). It is therefore important that the database accurately captures Antarctic ozone depletion, including its seasonal evolution and spatial distribution. The Arctic is also a key region where the role of ozone could benefit from further exploration. A data-sparse but potentially important region is the tropics. It was decided that total column ozone time series derived from the five different databases would be compared against an independent total column ozone time series by **V. Fioletov** to ensure that ozone trends in these regions are faithfully captured.

Altitude/pressure coordinates: Many databases are provided with altitude as the vertical coordinate. If this needs to be converted to a pressure based database, care must be taken when converting from altitude to pressure. Trends in stratospheric temperatures will produce a trend in the pressure *vs*. altitude relationship and if this effect is not accounted for, trends in pressure *vs*. altitude will alias into trends in ozone, especially in regions of strong temperature trends and strong vertical gradients in ozone. **G. Bodeker** will provide a transient altitude *vs*. pressure database to facilitate this conversion.

It was also recognised that temporal and/or spatial misalignment of the variability in the prescribed ozone database with the GCM internal dynamics could be problematic. Three such problems and their potential solutions are:

1) *Problem:* Because the database is a zonal mean database, zonal asymmetries in the model dynamics will not align with zonal asymmetries in the ozone field because there are none. While this may be important (Crook *et al*., 2008), it is more likely to be an issue for tropospheric rather than stratospheric ozone.
Possible solution: Provide the database as equivalent latitude zonal means, have the models calculate equivalent latitude online and sample the ozone database accordingly.

2) *Problem*: Any unforced variability in the GCM will not align with the unforced variability in the ozone database. For example, in the Arctic this could result in anomalously high ozone being prescribed in an anomalously cold stratosphere.
Possible solution: Exclude all unforced variability in the prescribed ozone database so as to reduce the extremes in the ozone time series. An alternative approach, although significantly more difficult to implement, would be to calculate ensemble statistics from the ozone database so that the model can temporally select from within a prescribed probability distribution function (PDF) according to the internal model PDF.

3) *Problem*: The tropopause inherent in the prescribed ozone database is unlikely to align with the internal tropopause in the GCM. For example, for an anomalously high tropopause in the GCM, this could result in stratospheric ozone levels being prescribed in the model upper troposphere.
Possible solution: Make the vertical coordinate of the ozone database kilometres above the tropopause.

The Working Group on Coupled Modelling (WGCM) were asked whether they would want to use any such dynamically referenced databases, but for AR5 it was decided that this would not be necessary. However, as discussed during the workshop, investigating the utility of such dynamically referenced databases would be best tackled by the SPARC DynVar activity.

Different 'Tiers' of database

It was decided that different tiers of the database would be constructed to meet the different needs of the modelling community.

Tier 0: Raw zonal mean monthly means covering as much as the globe as possible, for as long as possible. No missing values would be filled and any corrections applied to the data, *e.g*. to correct for inter-instrument differences, would be applied.

Tier 1: The four Tier 1 databases (see below) are all constructed based on regression model fits to the Tier 0 data, including different contributions from different model terms. Because the regression model can be evaluated for all months, the Tier 1 databases would have no missing data and would provide pole-to-pole coverage and span the tropopause to 50 km or higher. The intention is that it is only the Tier 1 databases that will be provided to CMIP5.

- *Tier 1.1 (Anthropogenic)*: Ozone from 1979 to 2006 constructed from the regression model mean annual cycle added to the contributions from the equivalent effective stratospheric chlorine (EESC) and linear trend basis functions. This database just aims to capture long-term secular changes in ozone.
- *Tier 1.2 (Natural)*: Ozone from 1979 to 2006 constructed from the regression model mean annual cycle added to the contributions from the quasi-biennial oscillation (QBO), solar cycle and El Niño basis functions.
- *Tier 1.3 (Natural & Volcanoes)*: The Tier 1.2 database but also including contribu-

tions from the El Chichon and Pinatubo volcanic eruption basis functions.

- *Tier 1.4 (All)*: Ozone from 1979 to 2006 constructed by summing the contributions from all of the basis functions included in the regression model.

Tier 2: A database that aims to be as close to reality as possible, *i.e*. full month-to-month variability. No missing data but clear flagging of where data have been filled.

Extending the database to 1850-2150

While it was not within the mandate of the SPARC workshop to discuss how to extend the observational database to years before 1979 and to years beyond 2006, some discussion was held on how this would be done. To extend the database into the past, the same regression model used to generate the Tier 1 databases will be used. This assumes that all required basis functions are available back to 1850 and that ozone-climate feedbacks do not significantly affect ozone over this period. To extend the database into the future, **V. Eyring** is working with **I. Cionni** to use the suite of CCM simulations available through CCMVal to create an ensemble of future simulations which will be spliced onto the end of the observational period.

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A SPARC Perspective on the World Modelling Summit

6-9 May 2008, Reading, UK

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The World Modelling Summit for Climate Prediction was held at the ECMWF (Reading, UK), May 6-9, 2008 under the auspices of the World Climate Research Programme (WCRP), and co-sponsored by the World Weather Research Programme (WWRP) and the International Geosphere-Biosphere Programme (IGBP). The key motivation for holding the Summit stems from the perceived need among climate scientists to rapidly advance the progress of climate modelling and prediction. This progress is essential in order to respond to the societal requests for information to aid decision-making regarding adaptation to and mitigation of climate change.

The Summit consisted of a number of high-level talks by invited speakers (2 days), followed by 1 day of discussion in breakout groups, and ended in a half day plenary section that reported the outcomes from the breakout groups, and merged their contributions into a consolidated statement. This statement was further discussed by the International Organizing Committee and resulted in the Summit Statement, posted on the web (**http://wcrp.ipsl.jussieu.fr/Workshops/ModellingSummit**), and published in a Bulletin of the American Meteorological Society article (Shukla *et al*., 2008). The event has also been reported in the scientific media (Heffernan, 2008).

Introductory talks focused on both the socioeconomic and environmental relevance of climate information, and on successful examples—from such wide-ranging disciplines such as high-energy physics and genetics—of international large-scale efforts to foster great advances in science. These talks then set the stage for addressing the challenges that the climate modelling community is now facing from a global perspective, in terms of infrastructure (computational facilities).

A broad range of topics was thereafter discussed by the invited talks, including:

- The seamless connection between weather and climate prediction
- Challenges for model development: very high resolution, parameterizations and stochastic aspects, biogeochemical cycles
- Best practice in experimental design: ensembles, glacial cycles with a carbon cycle model, multi-model approaches
- Complexity and uncertainty in climate change prediction
- Predictive uncertainty: The capability to predict uncertainty within a modelling system
- Climate prediction on decadal time scales
- Observational needs for initialising Earth System Models and for their evaluation
- Cloud-cluster resolving and cloud resolving models
- Status of climate modelling: limitations and improvements
- Quantification of improvements including

the value of using model metrics
- Need for process-oriented model evaluation
- Value and limitation of statistical and dynamical downscaling and "time slice" simulations with atmosphere-only models
- Hardware and software advances and their applicability to climate science

The themes of the breakout groups covered the topics of societal drivers, strategy for next generation modelling systems, hardware and software requirements, model evaluation and initialisation, and possible international frameworks for collaboration.

Given the focus of SPARC on climate processes, the discussions at the Summit are relevant to many aspects of our activities. Most pertinent is the need to advance the progress of climate research and modelling at a faster pace, a view which is also very much shared by the SPARC modelling community.

Another point in common is that the Chemistry Climate Models (CCMs) used by much of the SPARC community are closely connected to the current climate models. Specifically, the atmospheric dynamics and physical representation in the CCMs is in many cases shared with that of the atmospheric models used in coupled atmosphere-ocean global models, such as those used for climate projections made for the 4th assessment report of the IPCC. Advances in climate modelling would therefore be very beneficial to the current CCMs. Moreover, within SPARC, scientists are becoming aware of the need to go beyond atmosphere-only models (*albeit* coupled with chemistry), and instead use coupled atmosphere-ocean models as the core of their physical model systems. This step requires an even closer connection to the climate models, and to their improvements.

Some of the questions raised at the Summit, such as how to design models at ultra-high resolutions, also pose challenging questions to the modelling of the stratosphere. For instance, how would gravity-wave processes be represented in such models? Would the whole chain of causes and effects – from the generation mechanisms of the gravity waves to their propagation and dissipation – be properly simulated explicitly? Or would part of the processes in question still be in need of a parameterization? Clearly, new ways to address gravity-wave representation in models will have to be advanced, including their role in the initialisation of the models. Another related question is whether the current approaches to the parameterization of mechanical and thermal dissipation could be maintained, or if instead radically new ways for their modelling would need to be developed.

A question that many would pose to such high or ultra-high resolution models would be: How robust would the simulation of the Quasi-Biennial Oscillation (QBO) be? This question is of particular interest because the simulation of the QBO is a rather stringent test of the ability of a global model to represent tropical weather as a source of the upward propagating waves that give rise to the QBO. Given its non-linear dynamical nature, and its dependence on the generation, propagation and dissipation of atmospheric waves, for a global model run at a cloud-resolving resolution, the spontaneous occurrence of a realistic QBO would require that the multi-scale dynamical interactions on a very wide range of scales - from the cloud scale to the planetary scale - are properly represented.

The development of unified models (at the core of the seamless prediction approach) can benefit SPARC modellers – and SPARC modellers can contribute to such developments. These exchanges are indeed already occurring: The weather and data assimilation models are usually run at much higher vertical resolution and with higher tops than current climate models. Indeed, this is the rationale between the SPARC Data Assimilation Working Group.

The SPARC community has first-hand experience in modelling atmospheric chemical processes and related problems, such as the representation of transport. The SPARC CCMVal Activity is indeed actively exploring the use of performance metrics in stratosphere-resolving CCMs as part of a process-oriented evaluation. The role of complexity, including not only physical parameterizations but also atmospheric chemistry and biogeochemical cycles, in the climate models of the next generation was also discussed at various points in the Summit. The necessity of going beyond the prediction of the physical system, hence considering Earth System Models, was indeed clearly recognised. Given the focus of SPARC on ozone and its connection to climate, this is an important aspect where the SPARC experience could contribute to the advancement of knowledge for the prediction of the Earth System.

A specific challenge discussed at the Summit was the potential for decadal climate predictions that are expected to be skillful in selected regions. Here also the SPARC community can contribute its expertise concerning the role of the stratosphere in the climate system. Skillful predictions will depend on a realistic representation of the modes of climate variability, including stratospheric variability such as the QBO and sudden stratospheric warming events and their respective coupling to surface climate. Ozone recovery provides some predictability on the decadal time scale, and impacts surface climate through troposphere-stratosphere dynamical coupling. The dynamical coupling of the troposphere and stratosphere is indeed a SPARC Theme, and the DynVar Activity is addressing the climate model limitations associated with their vertical resolution and location of model top. The role of stratospheric variability and trends for skillful decadal prediction could be a new attractive research problem.

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Network for the Detection of Atmospheric Composition Change

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Introduction

The Network for the Detection of Atmospheric Composition Change (NDACC) is a set of more than 70 high-quality, remote-sensing research stations for observing and understanding the physical and chemical state of the stratosphere and upper troposphere. NDACC data is also aimed at assessing the impact of stratosphere changes on the underlying troposphere, and on global climate. NDACC was formerly known as the Network for the Detection of Stratospheric Change (NDSC), and commenced observations in 1991 with the aim of monitoring changes in stratospheric ozone, and the substances that lead to its depletion. The recent change of name reflects the considerable widening of the network's aims to detection of trends in overall atmospheric composition, understanding their impacts on the troposphere, and establishing links between climate change and atmospheric composition.

Information on the NDACC can be obtained from the NDACC home page (**www.ndacc.org**). This site provides a link to the public ftp database and also includes maps of the NDACC sites, instrument information, available data sets, and contact information. There is also access to the new 2008 NDACC Newsletter, which describes activities within each of the working groups, along with updates on scientific data analysis. This short article is to inform SPARC scientists of the existence of NDACC and the availability of data.

The principal goals of NDACC are:

- To study the temporal and spatial variability of atmospheric composition and structure in order to provide early detection and subsequent long-term monitoring of changes in the physical and chemical state of the stratosphere and upper troposphere; in particular to provide the means to discern and understand the causes of such changes.
- To establish the links between changes in stratospheric ozone, UV radiation at the ground, tropospheric chemistry, and climate.
- To provide independent calibrations and validations of space-based sensors of the atmosphere, and to make complementary measurements.
- To support field campaigns focusing on specific processes occurring at various locations and seasons.
- To produce verified data sets for testing and improving multi-dimensional models of the stratosphere and the troposphere.

These aims require high quality data and, accordingly, since the inception of the NDSC, much effort has been invested in instrument inter-comparison, calibration, and software validation. The result is a self-consistent data set suitable for addressing the above aims.

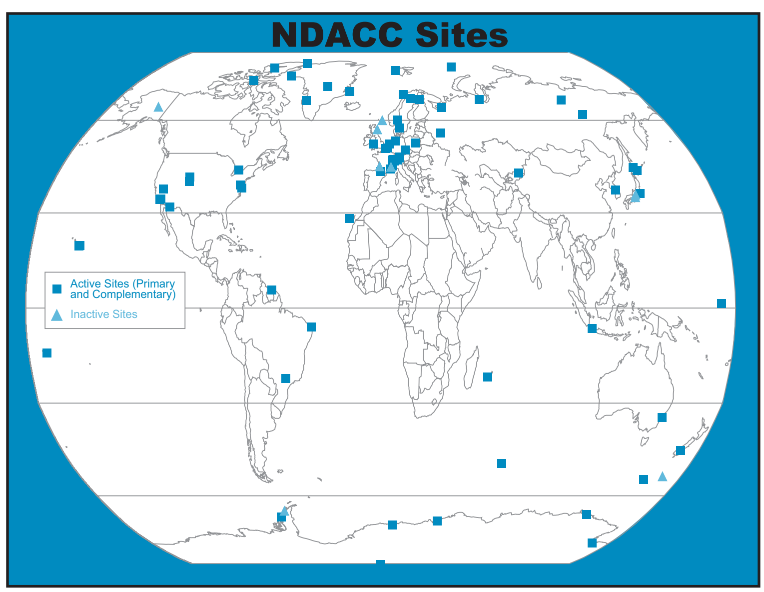
NDACC Database and Access

The NDACC database consists of ground-based and balloon-borne observations of ozone and other key species in atmospheric chemistry and climate. Ground-based column observations are obtained with Dobson, UV-visible, microwave, and Fourier Transform Infrared (FTIR) spectrometers. The list of species observed includes not only typical 'stratospheric' species, such as O_3, HCl, $ClONO_2$, ClO, NO, NO_2, HNO_3, HF *etc*., but also species of tropospheric relevance such as CO, OCS, HCN and CH_4 and other hydrocarbons. Ozone and temperature profiles are also obtained using lidar and sondes. In addition to these chemical measurements, the NDACC database includes observations of UV flux at the ground and supporting meteorological data.

In order to permit the widest possible usage, all data over 2 years old is made publicly available through an anonymous ftp server (details on www.ndacc.org). Users of these NDACC data should consult the on-line documentation and reference articles to fully understand the scope and limitations of the instruments and resulting data. Scientific users of the data are encouraged to contact directly the appropriate NDACC Principal Investigator (listed in the data documentation on the web page) to ensure the proper use of specific data sets. The PI can also be contacted if you wish to use data less than 2 years old.

Acknowledgements

Because of its worldwide dimension, the NDACC has been recognised as a major component of the international atmosphere research programme. As such, it has been endorsed by national and international scientific agencies, including the United Nations Environmental Programme (UNEP) and the International Ozone Commission (IO3C) of the International Association of Meteorology and Atmospheric Physics (IAMAP). It has also been recognised by the World Meteorological Organization (WMO) as a major contributor to WMO's Global Ozone Observing System (GO3OS) within the frame of its Global Atmosphere Watch (GAW) Programme.



2009

Future SPARC and SPARC-related Meetings

11-15 January	**89th AMS Annual Meeting**, Phoenix, AZ, USA, http://www.ametsoc.org/MEET/annual/index.html
19-24 April	**European Geosciences Union General Assembly 2009,** Vienna, Austria, http://meetings.copernicus.org/egu2009/
28-29 April	**DynVar Workshop,** Hamburg, Germany, http://www.sparcdynvar.org/
4-8 May	**Third THORPEX International Science Symposium,** Monterey, CA, USA, http://www.wmo.int/thorpex
24-27 May	**AGU: 2009 Joint Assembly,** Toronto, Canada, http://www.agu.org/meetings/ja09/
31 May - 4 June	**43rd Annual CMOS Congress,** Halifax, Canada, http://www.cmos.ca/Congress2009/
1-3 June	**CCMVal Workshop 2009,** Toronto, Canada, http://www.pa.op.dlr.de/CCMVal/
8-12 June	**15th AMS Conference on Middle Atmosphere,** and **17th Conference on Atmospheric and Oceanic Fluid Dynamics,** Stowe, VT, USA, http://www.ametsoc.org/MEET/fainst/200917fluid15middle.html
19-29 July	**IAMAS Assembly,** Montreal, Canada, http://www.moca-09.org/index.asp

Themes and Activities

Climate-Chemistry Interactions: T. Peter (Switzerland), A. R. Ravishankara (USA)

Stratosphere-Troposphere Dynamical Coupling: M. Baldwin (USA), S. Yoden (Japan)

Detection, Attribution, and Prediction of Stratospheric Change: W. Randel (USA), T.G. Shepherd (Canada)

Gravity Waves: J. Alexander (USA)

Data Assimilation: S. Polavarapu (Canada)

CCM Validation Activity (CCMVal): V. Eyring (Germany), D. Waugh (USA), A. Gettelman (USA), S. Pawson (USA), T.G. Shepherd (Canada)

Laboratory Studies joint with IGAC: A.R. Ravishankara (USA), R. A. Cox (IGAC)

Solar Influences for SPARC (SOLARIS): K. Kodera (Japan), K. Matthes (Germany)

Dynamical Variability Activity: P. Kushner (Canada)

UTLS/SPARC Tropopause Initiative: P. H. Haynes (UK), A. Gettelman (USA), M. Geller (USA)

The Role of Halogen Chemistry in Polar Stratospheric Ozone Depletion: M.J.Kurylo (USA), B.-M. Sinnhuber (Germany)

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