SPARC
STRATOSPHERIC PROCESSES AND THEIR ROLE IN CLIMATE
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Greeting from the new co-Chairs of SPARC

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We feel honoured and excited to be taking on the role of SPARC co-Chairs. Both of us have been involved in SPARC for many years, and have been inspired by the leadership provided by the past co-Chairs: first Marie-Lise Chanin and Marv Geller, and more recently Alan O'Neill and A. R. Ravishankara. By keeping SPARC focused on "bite-sized" deliverables that are responsive to the needs of the scientific community, by crossing disciplinary boundaries and forging new partnerships, by engaging the leading scientists internationally, and by continually renewing SPARC to drive the scientific agenda, they have set the standard for a successful and effective international project. We must also acknowledge the tremendous support that has been provided by the SPARC Office, first in Paris under the Directorship of Marie-Lise Chanin, and more recently in Toronto under Norm McFarlane. They have established the SPARC Newsletter as a "must read" publication which boasts thought-provoking articles of the highest scientific calibre. Through all these efforts, SPARC has established an enviable reputation for high-quality climate science which is innovative, inter-disciplinary, and exciting.

Our goal for SPARC is to build on these achievements by remaining true to the guiding principles that have made SPARC so successful up to now. The future directions of SPARC will involve a closer integration with tropospheric climate science, in terms of both chemistry-climate coupling and stratosphere-troposphere dynamical coupling. In this respect, we look forward to an ever-deepening interaction with IGAC, and with other components of WCRP. The challenge will be to achieve this while maintaining the inter-disciplinarity — where chemists talk with dynamicists, and where data assimilators talk with process-oriented scientists — that has been the hallmark of SPARC, and has made it so much fun.

We look forward to working with all of you.

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Report on 28th Session of the JSC Zanzibar, Tanzania, 26-30 March 2007

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The Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP[1]) meets annually to review progress and decide on future directions. This year's JSC meeting was held in Zanzibar, Tanzania, and was hosted by the Tanzanian Meteorological Agency. The middle day of the meeting was devoted to a workshop on climate science in Africa, which attracted both young and well established African scientists, and included a panel discussion on networking and research needs chaired by the Tanzanian Minister of the Environment, the Hon. Prof. Mark Mwandosya.

One of the first actions of the JSC was to approve the nominations of Tom Peter (ETH Zürich) and Ted Shepherd (University of Toronto) as the new SPARC co-Chairs with immediate effect. The outgoing co-Chairs, Alan O'Neill and A. R. Ravishankara, were deeply thanked for all they had contributed to SPARC and WCRP over the years.

Challenges faced by the WCRP

There was considerable anticipation before this year's session, because the WCRP is facing a number of challenges including an expected severe shortage of resources to support coordination activities. While a significant part of this funding shortfall is due to the decline in value of the US dollar in recent years, the fact remains that the sponsor funding has been slowly declining in real terms. There appears to be a widespread feeling among research sponsors that there is an ever-growing "alphabet soup" of organizations crying out for financial support of climate research, and that some sort of rationalization is required. Thus, for example, the advantages of a merger between WCRP and IGBP (the International Geosphere-Biosphere Programme) are being seriously discussed. At the same time, governments everywhere are increasingly concerned about "value for money" and requiring more demonstrated impact of their research investments. In this respect, it has been noted that WCRP is nearly invisible in the public eye as compared with the IPCC, even though WCRP-facilitated research has made such an enormous contribution to the IPCC reports. Finally, there also appears to be a growing perception in governments that, with the now essentially universal acceptance of the reality of global warming, the need for additional research on climate science is over and efforts need to be directed instead to fundamental science on impacts and adaptation, as well as mitigation.

In the light of these challenges, it was felt that for the WCRP to continue "business as usual" was not a viable option, and that some changes in approach were required. The very spirited discussions that took place throughout the week were conducted in this context. There seemed to be general agreement that there was scope for WCRP to improve its visibility with more active communication of its specific achievements. The WCRP Joint Planning Staff was thanked for significantly improving the Programme's website and keeping it updated, and launching several outreach actions such as the new Electronic newsletter eZine and the News sections on the website. There was a consensus that in order to convince governments and sponsors of the need for WCRP-facilitated research, all WCRP activities need to take an end-to-end view of their research programmes by identifying and documenting specific deliverables and outcomes. The main points of discussion concerned how best this could all be done. The COPES (Coodinated Observation and Prediction of the Earth System) framework had been introduced by the JSC several years ago in an effort to provide more integration of and visibility for WCRP activities, but there appeared to be some confusion as to what COPES actually meant in practice. Conversely, there was broad agreement at the JSC meeting that many of the individual activities of the core projects are very well placed in this respect and already taking an end-to-end view, and that this also started to apply to the several "cross-cutting initiatives" that formed the centre-piece of the agenda of this JSC session.

It was noted by many speakers that the lion's share of WCRP-facilitated research was carried out by the four WCRP core projects (CliC, CLIVAR, GEWEX and SPARC), and that the funding raised through the core projects represents a many-fold leveraging of that provided to the WCRP from its sponsors. Certainly, when assessing the financial situation and outreach of the WCRP the entire package needs to be considered, and any changes in WCRP structure made in that light. In particular, the core projects have established quality "brands", which are valuable assets when it comes to obtaining funding. It was also noted in this respect that the core projects were in an excellent position to be responsive to the specific needs of governments, expressed through their national and regional funding agencies, as they have direct links with those agencies for their various funded activities. Similar remarks apply to the other precious, and increasingly stretched, commodity — the time of leading scientists who participate in WCRP activities on a voluntary basis.

While there are a number of topical cross-cutting research initiatives which help to build bridges between the core projects, it is clear that the funding agencies would have little appetite for supporting additional infrastructure (such as project offices) which would duplicate the infrastructure

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[1]The WCRP is jointly sponsored by the World Meteorological Organization (WMO), the International Council for Science (ICSU) and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. (For more information: **http://wcrp.wmo.int/**).

already existing in the core project offices. Nor would it be easy to find additional scientific leadership. Thus, the decision was made by the JSC to have the cross-cutting initiatives run through the core projects, with particular core projects taking the lead within WCRP: "Decadal prediction" and "Seasonal prediction" will be led by CLIVAR, "Extreme events" and "Monsoons" jointly by CLIVAR and GEWEX, "International Polar Year" by CliC, and "Atmospheric Chemistry & Climate (AC&C)" by SPARC together with IGAC of IGBP (see below).

Each of the core projects has a presently anticipated phase-out in the range 2012-2015, and between now and then it is imagined that the cross-cutting initiatives may well define the roadmap for the future of the WCRP. In addition, the exact configuration of all this will depend on future cooperation between WCRP and IGBP.

Report on SPARC

The annual report on SPARC activities was prepared by both the outgoing and the incoming SPARC co-Chairs together with the SPARC Office Director, Norman McFarlane, and was presented by Ted Shepherd. Given that there was a "changing of the guard" in the SPARC co-Chairs, some historical perspective was provided. It was noted that SPARC's modus operandi had always involved identifying "bite sized" deliverables and working together with the relevant partners, whether inside or outside WCRP, to ensure maximum impact. One of the main vehicles for this has been SPARC reports, which are fully peer reviewed and have provided direct input into the last three WMO/UNEP Ozone Assessments. SPARC reports have been cited 45 times in the Web of Science, 18 times in the IPCC TAR, and 22 times in the 2002 Ozone Assessment. Other vehicles for impact include refereed review papers, inter-disciplinary workshops to cross boundaries, and targeted working groups.

SPARC's science themes have continually evolved as the science has evolved. Whilst SPARC was originally largely dynamics-oriented, in the last 5 years it has "pushed the science envelope" in a number of ways: it has recognized the need for coupled chemistry and paved the way for AC&C (see below) with the Chemistry-Climate Model Validation activity (CCMVal); it has initiated and led efforts on two-way stratosphere-troposphere coupling and its relevance to predictability; it has recognized the importance of data assimilation for climate studies and brought the academic community into this subject; it has recognized the importance of cloud-resolving models for interpreting high-resolution measurements in the UTLS region; and it has recognized the need to understand and quantify dynamical variability for stratospheric climate change assessment and prediction. These scientific developments are reflected in the current portfolio of SPARC activities.

A major current thrust of SPARC is CCMVal. CCMVal defined the forcings and simulation protocols for the chemistry-climate reference runs that provided a major underpinning for the 2006 Ozone Assessment. As the questions being asked of the Ozone Assessment increasingly involve the coupling between ozone depletion/recovery and climate change, the use of CCMs is becoming increasingly important. These CCMVal runs 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 runs were analysed in two major community publications (Eyring *et al*., 2006; 2007) and several more publications are currently in preparation. CCMVal is currently embarking on a SPARC report, which will be completed in the summer of 2009 and is being designed to provide direct input into the expected 2010 Ozone Assessment and IPCC AR5. The community response to this initiative has been tremendous, with all 18 Chapter Lead Authors who were approached agreeing to serve in that capacity. The 2007 CCMVal workshop to be held in Leeds, UK, will serve to launch the report.

A new initiative launched at the 2006 SPARC SSG was the Dynamical Variability activity, DynVar (see article in this newsletter), led by Paul Kushner of the University of Toronto. The goal of DynVar is to utilize a range of modelling approaches to address the representation of the stratosphere in climate models — specifically, how well do we need to resolve the stratosphere for accurate climate assessment? — as well as the impact of the stratosphere on both climate variability and climate change. The science plan for this activity has been under development since the last SSG meeting; one of the first steps will be to re-do the CLIVAR C20C simulations with "high-top" models. This activity will link to several of the WCRP cross-cutting activities, namely seasonal and decadal prediction and climate extremes.

Several important SPARC workshops took place in 2006. Notable among these were the joint workshop with GEWEX-GCSS and IGAC on modelling of deep convection and chemistry and their roles in the tropical tropopause layer (TTL), held in Victoria, Canada. A small working group is currently developing plans on how to move this activity forward. The annual workshop of the SPARC Data Assimilation Working Group was held in Noordwijk, Netherlands. Finally, the first SOLARIS (SOLAR Influence for SPARC) workshop was held in Boulder, USA. This is a collaborative activity with the SCOSTEP CAWSES activity, and will feed into the CCMVal report as well as future WMO/UNEP and IPCC assessment activities.

International Polar Year (IPY) has now begun, and the SPARC-IPY activity — The Structure and Evolution of the Polar Stratosphere and Mesosphere and Links to the Troposphere during IPY — is thus officially underway. Funding has been obtained through two Canadian agencies (NSERC, CFCAS) to support coordination of SPARC-IPY activities through the SPARC Office. The first SPARC-IPY workshop will be held in Toronto in conjunction with the next SPARC DAWG workshop during September 4-7, 2007.

SPARC could not function without the SPARC Office. Funding has now been secured from CFCAS to both enhance the current operations and ensure the funding of the SPARC Office in Toronto through 2010. The semi-annual SPARC Newsletters continues to provide timely and informative material; articles in the Newsletters have been cited 143 times in the Web of Science. Finally, planning for the fourth SPARC General Assembly, to be held in Bologna, Italy from September 1-5, 2008 is now well underway.

The JSC commended SPARC for its focus on "bite sized" and "end-to-end" deliverables, including its high-impact reports, for its forward-looking orientation, and for its ability to bridge between the climate and weather prediction communities. It was noted that the evident willingness of the scientific community to devote their own time and resources to SPARC was the surest sign of the value of its activities. While the role of SPARC in the Task Force on Seasonal Prediction was recognized, SPARC was encouraged to develop a stronger link to the WCRP cross-cutting activity on Monsoons and the Year of Tropical Convection.

Report on SPARC's "Atmospheric Chemistry & Climate" (AC&C) initiative

AC&C is a cross-cutting initiative run by SPARC and IGAC (International Global Atmospheric Chemistry project) on behalf of WCRP and IGBP, respectively, whose goal is to improve the understanding and representation of chemical processes in climate. The report on AC&C to the JSC in Zanzibar had been prepared by A. R. Ravishankara from SPARC and by Phil Rasch and Sarah Doherty from IGAC, and was presented by Tom Peter. AC&C was launched at the March 2006 JSC meeting: a small workshop in Boulder, USA in August 2006 laid the groundwork for the basic structure and goals of the initiative, and an open workshop in Geneva, Switzerland in January 2007 engaged the larger community and established an implementation plan for Phase I. AC&C will tackle problems at the interface of climate change, atmospheric chemistry, and air quality and health, and will also investigate "win-win" options and "win-lose" consequences. AC&C's premise is that a model emphasis will increase our ability to represent processes in an integrative context and will provide the target for contributions by observations and theory. Details of AC&C including a timeline have been described by A. R. Ravishankara in SPARC Newsletter No. 27. AC&C will build on the existing CCMVal (stratospheric chemistry) and AeroCom (tropospheric aerosols) activities, and develop a corresponding activity in tropospheric gas-phase chemistry (tentatively called TropChem to be consistent with AC&C). The three activities will share resources and organizational structures, and link through cross-cutting research activities, each of which will have their own steering committee. The goal in Phase I is to coordinate the modelling activities so as to be completed in time for the expected IPCC AR5.

The report on AC&C was unanimously received with great interest and appreciation for the work done to date. It was acknowledged by a number of JSC members that this was a very well designed initiative, of prime scientific interest, well suited for outreach, and optimally accommodated under the core projects SPARC and IGAC. Finally, AC&C was also acknowledged as a bridgehead between WCRP and IGBP which might gain particular importance in a potential common future of the two programmes.

The future of SPARC

SPARC was established in 1992 by WCRP because it was felt that the role of the stratosphere in climate was not receiving sufficient attention. From the very beginning, it was argued that SPARC would come to an end when the stratosphere was regarded as an integral part of the climate system. While good progress has been made over the past 15 years in approaching this goal, it is clear that stratospheric — and for that matter also upper tropospheric! — research has not yet become "mainstream" within climate research. As described above, SPARC is presently proactively driving an exciting set of new directions which are at the leading edge of climate research, and which will change the nature of the field. We will have to see as the coming years unfold whether the traditional approach of SPARC continues to be optimal, or whether a different orientation and focusing, *e.g.* in favour of one or more of the WCRP cross-cutting activities, is better suited to advancing SPARC science. With AC&C and its other activities SPARC is already now well prepared for such a development. But in the meantime, there is plenty of good work to be done!

References

Eyring, V., N. Butchart, D. W. Waugh, H. Akiyoshi, J. Austin, S. Bekki, G. E. Bodeker, B. A. Boville, C. Brühl, M. P. Chipperfield, E. Cordero, M. Dameris, M. Deushi, V. E. Fioletov, S. M. Frith, R. R. Garcia, A. Gettelman, M. A. Giorgetta, V. Grewe, L. Jourdain, D. E. Kinnison, E. Mancini, E. Manzini, M. Marchand, D. R. Marsh, T. Nagashima, P. A. Newman, J. E. Nielsen, S. Pawson, G. Pitari, D. A. Plummer, E. Rozanov, M. Schraner, T. G. Shepherd, K. Shibata, R. S. Stolarski, H. Struthers, W. Tian, and M. Yoshiki, Assessment of temperature, trace species and ozone in chemistry-climate model simulations of the recent past, *J. Geophys. Res*., 111, D22308, doi:10.1029/2006JD007327, 2006.

Eyring, V., D.W. Waugh, G.E. Bodeker, E. Cordero, H. Akiyoshi, J. Austin, S.R. Beagley, B. Boville, P. Braesicke, C. Brühl, N. Butchart, M.P. Chipperfield, M. Dameris, R. Deckert, M. Deushi, S.M. Frith, R.R. Garcia, A. Gettelman, M. Giorgetta, D.E. Kinnison, E. Mancini, E. Manzini, D.R. Marsh, S. Matthes, T. Nagashima, P.A. Newman, J. E. Nielsen, S. Pawson, G. Pitari, D.A. Plummer, E. Rozanov, M. Schraner, J.F. Scinocca, K. Semeniuk, T.G. Shepherd, K. Shibata, B. Steil, R. Stolarski, W. Tian, and M. Yoshiki, Multi-model projections of stratospheric ozone in the 21st century, *J. Geophys. Res.*, accepted, 2007.

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"Atmospheric Chemistry and Climate": A New IGBP-IGAC/WCRP-SPARC Initiative

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Background

A significant part of the current human-induced climate forcing occurs through chemically active species. Changes in climate can lead to changes in the chemical composition of the atmosphere both by altering emissions and through changes in the chemical processes that occur in the atmosphere. The study of climate-chemistry interactions represents one of the most important and, at the same time, most difficult foci of global change research. Further, chemically active species are more amenable to short term manipulations through changes in emissions and are therefore of major policy relevance. Changes in emissions themselves can be brought on by climate trends or a change in climate variability. These factors also feed into the emerging issue of the coupling of climate and air quality, from both scientific and policy perspectives. Provision of high-quality, policy-relevant information on the current state of climate and its possible future states, as well as options for mitigation / control / change / adaptation are strongly dependent on the progress in studies in this area.

In addition, at least two major assessments – The World Meteorological Organization (WMO) Ozone Assessment and the Intergovernmental Panel on Climate Change (IPCC) climate change Assessment – would benefit by improved understanding of chemistry-climate interactions; such improvements would help society through better information and policy. Significant progress to this end has been made through SPARC's Chemistry Climate Model Validation (CCMVal) effort, which has focused specifically on stratospheric chemistry-climate models and has fed directly into the latest WMO/UNEP International Ozone Assessment. Additional progress can be made by coupling this effort with studies using tropospheric chemistry-climate models and through coordinated studies with tropospheric chemistry-climate and aerosol models. The next IPCC assessment needs better information on emissions and abundances to address not only global climate change attribution but also the needed regional emphases for attribution and predictions. Improvements to the representation of these species in chemistry-climate models will also allow for better representation of the climate system in global models.

Because of the importance of chemistry-climate interactions, much work is already going on in this area. Modelling centers are rapidly expanding the scope of their modelling efforts (for example, to include biogeochemical processes at the surface, chemical processes in the troposphere and middle atmosphere, and the impact of each of these on climate). Within IGAC, a project of IGBP, efforts to date have focused primarily on constraining atmospheric chemistry components and processes through measurement. Within WCRP's SPARC project, the focus has been on modelling activities in the middle atmosphere with less emphasis on field experiments of chemistry and chemical processes and the troposphere. The steering groups of SPARC and IGAC and their parent organizations, WCRP and IGBP, believe that a synergy would result from a coordinated effort by the SPARC and IGAC communities that focuses specifically on the representation of chemistry-climate interactions in Earth System Models. This effort would both be informed by inputs from the observational community (*in-situ* and remote sensing) and would help inform decisions about how to optimize future measurement campaigns.

AC&C Goals

The "Atmospheric Chemistry and Climate Initiative" (AC&C) was endorsed in March 2006 as a joint effort of WCRP and IGBP, with the SPARC and IGAC projects tasked to take the lead in its implementation. An initial scoping meeting for the Atmospheric Chemistry and Climate Initiative (Boulder, Colorado; August, 2006) laid the groundwork for the basic structure and goals of the Initiative. Using this as a starting point, a first set of AC&C activities, more specific goals, and a time-line were set at the 1st AC&C Workshop, which was held in January 2007 in Geneva, Switzerland.

AC&C will be implemented in phases, with the first phase planned to end in 2009. In Phase I, the primary focus will be on improving process representation in chemistry-climate models but the effort will also be useful for Earth system and regional/global air quality models. The role of the AC&C project is coordination, in that it is not an independently funded effort. The mission of AC&C is to help the scientific community to define a common set of scientific themes and facilitate their execution once defined. Some of this coordination will involve defining new activities. Other advances on aspects of this problem will be made by connecting to and influencing the direction of several existing activities linked to AC&C – *e.g.* the Chemistry-Climate Model Validation activity of SPARC (CCMVal), the global Aerosol model inter-Comparison (AeroCom), the European ACCENT project Model InterComParison (ACCENT-MIP), and the Task Force on Hemispheric Transport of Atmospheric Pollutants[1] (TF HTAP). CCMVal is a model inter-comparison and validation effort for stratospheric chemistry-climate models. Under AeroCom, global tropospheric aerosol models were compared and tested against satellite, lidar, and sun photometer measurements. The ACCENT-MIP effort previously focused on coordinating and comparing IPCC scenarios, contrasting the climate between 2030 *vs*. 2000 across

[1]The Task Force on Hemispheric Transport of Air Pollution is set up under the auspices of the Convention on Long-range Transboundary Air Pollution. More information is available on **www.htap.org**

a suite of tropospheric chemistry-climate models, with an eye toward capturing how climate change might affect air quality (gas species only). This effort has now been extended to encompass the activities of the TF HTAP. The TF HTAP activities focus on understanding and quantifying Northern Hemispheric transport of gaseous and particulate air pollutants and their precursors from source to receptor region.

For all of these activities and for the AC&C objectives in general, emissions characterization (time-history, uncertainty, *etc*.) are of critical importance. Therefore, the IGBP-AIMES Global Emission Inventory Activity (GEIA) and other emissions activities will also be associated with AC&C.

AC&C activities involve:

- identifying a set of science questions around atmospheric chemistry and climate that require integration and synthesis across the projects;
- identifying atmospheric processes that are both important to addressing key science questions and yet which remain poorly understood;
- identifying a set of common diagnostics that can be used to address these uncertainties;
- coordinating the modelling and measurement communities so that the measurements can be used more effectively to constrain the models and so that models can be used to inform measurement planning;
- facilitating the development of improved representations for critical processes; and
- helping to define common model output and data conventions, file formats, and perhaps the establishment of data portals or data centres for model outputs and observations.

At the first workshop in Geneva, leaders from CCMVal, AeroCom, ACCENT-MIP, TF HTAP and GEIA were asked to give overviews of their project, with an emphasis on how the activity relates to the goals of AC&C and on how the AC&C initiative might benefit that activity. There were several resounding messages on this latter point:

Physical system interdependencies

The science within each project would benefit through cross-fertilization with related projects, given the inter-dependencies of the different components of the system – for example, the physical connections between the troposphere and stratosphere and between the aerosol and gas phases of atmospheric chemistry. To date, there have been largely separate efforts addressing stratospheric chemistry, tropospheric gas phase chemistry, and tropospheric aerosols. The science and models have recently become sufficiently advanced to address these "compartments" as a single system.

Emissions inventories

An overarching activity such as AC&C could be used to promote an expansion and a thorough evaluation of emissions inventories. Current emissions inventories are effectively a database, with little or no accompanying meta-data and little effort in assessing the characteristics of the inventories for any given applications. GEIA has a strong activity in assembling emission inventories relevant to atmospheric chemistry and climate. There are also efforts (*e.g* within the TF HTAP community) that focus on emissions for air quality research, and efforts from the socio-economic scenarios community to produce future emissions scenarios. A systematic assessment of uncertainties, harmonization of the emissions databases, and the addition of meta-data about how the inventory was derived, what applications are it useful for, *etc*., would be highly beneficial to this community and for the other communities, such as for model evaluation and for process-related field studies. Furthermore, by helping to define the criteria by which the modelling community judges these inventories we might influence the methodologies used to produce next generation inventories.

Common database and tools for model output

Within each of the existing projects (CCMVal, AeroCom, ACCENT-MIP, TF HTAP) a common data format has been established; however, the chosen data format differs between some of these projects. It would be beneficial to have a common data centre (even if it were only a "virtual" link), a single formatting standard, a set of visualization tools that could be utilized across the whole community, and a single meta-database with information on the models themselves.

Observational/Laboratory data sets

First steps have been made within the existing projects to go beyond model intercomparisons, *e.g.* to model evaluation *via* comparison with observations/measurements. However, in many cases the comparisons help reveal which models might be in error but do not provide information on which model processes are causing the error. In addition, the observations themselves might be biased, making results sometimes inconclusive. Therefore a comprehensive comparison to multiple types of observations/measurements is needed, and these comparisons should be crafted wherever possible to reveal information about the performance of processes in models. Barriers to achieving this include a lack of understanding within each community of what the other needs or can provide, and where to go for information; the lack of a centralized, standardized observational database that includes information on data quality/uncertainties and other meta-data; difficulties around mis-matches in the scales (spatial and temporal) of model output *versus* measurements; and differences in the model input and output parameters *versus* those physical parameters that are measured. Under AC&C, some of these barriers could be overcome through coordination of the relevant communities.

Need for advanced planning and "legwork" to meet assessment demands

It was clear to the participants that advanced planning, preparation, and initiation of activities help a better assessment and are essential for the science community. There is so little time between assessments, and there is a serial nature to the sequence of events that lead to the assessments, so that any planning and preparation is greatly helpful. In some cases, chemistry model runs have to be done even as climate runs are carried out. AC&C provides a pathway for the international scienctific community to carry out this early work.

Phase I Activities & Structure

The activities of AC&C will be pursued under the organizational framework given in **Figure 1**. This framework has been presented to the governing bodies of both IGBP and WCRP; they have both accepted and endorsed this approach. Two existing activities – CCMVal and

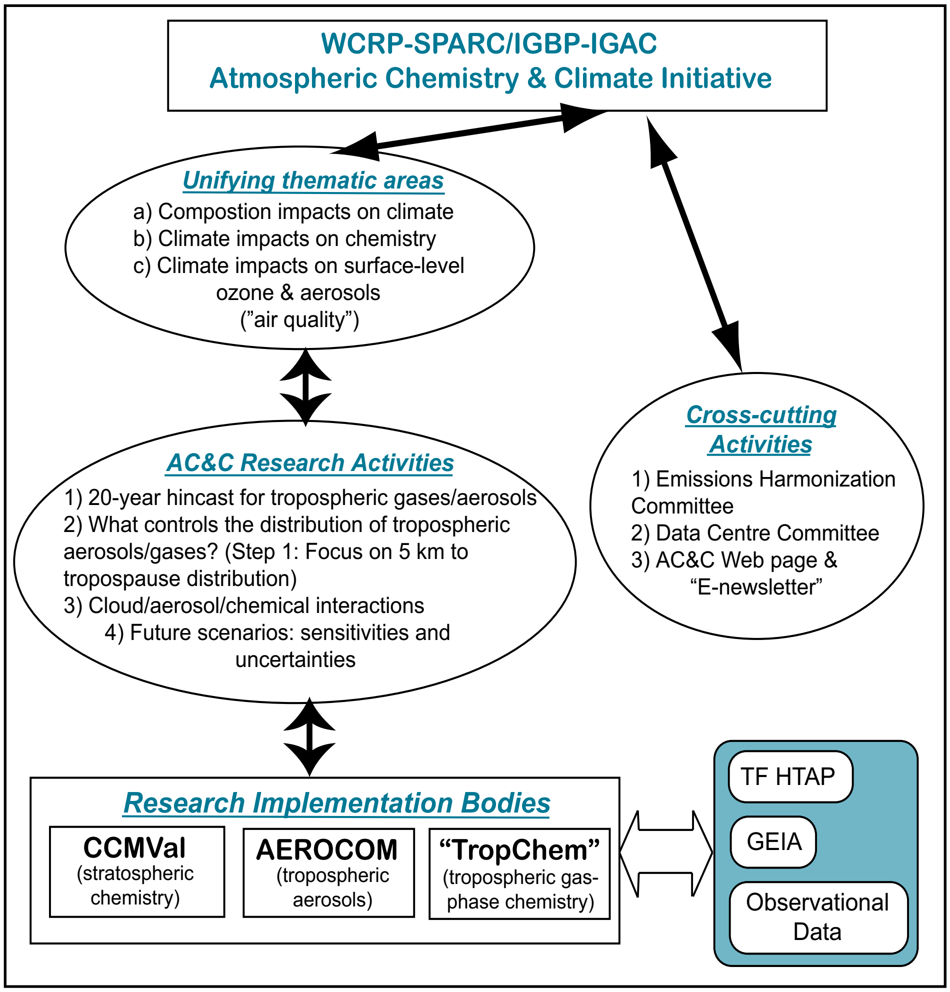

Figure 1

AeroCom – cover two of the areas of interest under AC&C: stratospheric chemistry and tropospheric aerosols. A third area of interest, tropospheric gas phase chemistry, is covered only in part by other activities (*e.g*. ACCENT-MIP/TF HTAP). Thus, a new group, dubbed "TropChem", will act as a liaison to the gas-phase tropospheric chemistry/climate modelling community and will build on existing activities such as under TF HTAP and ACCENT-MIP. These three groups will act as the Research Implementation Bodies for AC&C activities. It should be emphasized that the activities of AC&C will comprise *components* of the science pursued by CCMVal and AeroCom and will require buy-in from these projects' communities. As discussed below, AC&C activities were selected with this in mind.

In Boulder, three thematic areas were decided on for AC&C: the impacts of climate on atmospheric chemistry; the impact of atmospheric chemistry on climate; the impact of climate on air quality. As AC&C is an unfunded activity, improvements in each of these areas will only be made through the efforts of independently funded research groups. Thus, its success is contingent on buy-in from the scientific community and on being able to take advantage of already-planned or existing activities/model runs. Given limited time and financial resources, not all aspects of these thematic areas can be addressed simultaneously. Conversely, activities under AC&C – which is by definition a coordination activity – should require the participation of three or more modelling groups and two or more of the Research Implementation Bodies. Thus, discussions in Boulder and at the 1st AC&C Workshop focused on selecting a set of activities based on scientific questions that:

- have a high scientific priority;
- are likely to be tractable;
- are likely to be of interest to/addressed by a large number of research groups;
- as a collection, address a breadth of tropospheric and stratospheric processes critical to chemistry/climate interactions;

Additionally, the policy-relevance of AC&C is recognized. In particular, activities were chosen in consideration of the upcoming WMO Ozone Assessment and recognizing the likelihood of another IPCC assessment, with the desire for the activities of AC&C to inform these assessments. Using the above criteria, four projects were selected in Geneva for pursuit under AC&C in Phase I of the project (nominally to end in 2009):

Activity 1: A 20-25 year hindcast of tropospheric ozone and aerosols.
Activity 2: Defining what controls the distribution of aerosols/gases in the atmosphere, initially focusing on distributions in the troposphere between 5 km and the tropopause.
Activity 3: Better representation of cloud, aerosol, and chemical interactions.
Activity 4: Analyses of sensitivities and uncertainties in the future scenarios for climate models.

In addition, a *Data Center Committee* was formed to explore issues/options for having a centralized data centre/tools under AC&C and an *Emissions Harmonization Committee* was formed to work with GEIA and HTAP to try and improve the utility of emissions databases for use by models.

It was decided that there would *not* be a centralized effort to consolidate observational data sets as a general task of AC&C, as this is beyond the scope, capability, and resources of the initiative. Instead, observations and laboratory data will be utilized within each of the four AC&C activities as appropriate for validating and understanding model processes and output and as a way of increasing our ability to represent processes in models. The observational and laboratory community will be engaged in each of the AC&C activities for this purpose.

In Geneva, broad outlines were drawn up for each of the AC&C Activities, and draft steering committees were established. These committees are currently working on the details of how each activity will proceed. Below, brief descriptions of each, as defined at the 1st AC&C Workshop, are given.

ACTIVITY 1:
20 Year Hindcast Simulation

Five or more models would do a 20-25 year "hindcast" to address the questions:

- Can we replicate the observed changes

- in chemical composition over the past 20 years?
- Can we understand what processes have acted to change the tropospheric chemistry of the atmosphere, particularly ozone and aerosols?

Model results would be compared with each other and with available observations to assess where uncertainties lie. The 20 year run would be designed to incorporate special "focus" or "snapshot" periods; *e.g*. El Nino *vs*. La Nina years, periods when field campaign data are available for ground-truthing, *etc*. To the best degree possible, everyone would run with the same anthropogenic emissions. Diagnostics would be designed to reveal information on model processes. Such an experiment can be based on experiences gained from the European RETRO project, in which 3 global models have simulated the period 1960-2000 and investigated changes in tropospheric ozone and its precursors.

ACTIVITY 2: What controls the distribution of aerosols/gases in the troposphere?

Step #1: Investigate what controls the distribution between 5 km and the tropopause.
> *This activity would contribute to the next WMO Ozone Assessment*
The upper troposphere was chosen as an area of interest because a) the processes that control trace constituents in this region differ from model to model, and this results in dramatic differences in the distributions themselves from model to model; b) species in this altitude range (*e.g*. ozone, dust, black carbon) can have a significant radiative impact and may affect other components of the climate system (like cirrus clouds); c) the processes that control the distribution of species in this altitude range (*e.g.* vertical lofting; wet deposition; cloud processing) also control the long-range transport of these species; and d) the distribution of species in this region depends on and influences processes in the upper troposphere/lower stratosphere.

ACTIVITY 3: Cloud, Aerosol, Chemical Interactions

This activity will address the question: How well can we characterise warm cloud / aerosol interactions in global models, with a specific focus on the interactions with gas chemistry photochemistry? It will explore the impact of aerosols on atmospheric chemistry through their modification on clouds. This would be done employing a paradigm of controlling iterative sets of parameters (cloud droplet number, *etc*.) during model runs, slowly adding in links to aerosols and investigating the impacts on chemistry in clouds.

ACTIVITY 4: Future scenarios: Sensitivities & Uncertainties

> *This activity would contribute to the next IPCC Assessment*
The goal here would be specifically to have a better representation of aerosol and chemistry in the next IPCC Assessment Report 5 (AR5; should there be one). This group could define the pre-industrial to present to future scenarios, based on emissions that are consistent with other AR5 runs (to the best degree possible). By running multiple models with constrained emissions, it would be possible to define a "best guess" and uncertainties. The model runs would further be designed to explore sensitivities to model processes.

If you are interested in participating in one of the AC&C activities or have other input, please contact Sarah Doherty of the IGAC Seattle Core Project Office (**igac.seattle@noaa.gov**) or go to the website at **http://www.igac.noaa.gov/ACandC.php**.

Boulder AC&C Initial Planning Meeting Attendees:
Mary Barth *(NCAR-ACD)*, Guy Brasseur *(NCAR-ACD)*, William Collins *(U.K. Met Office)*, Sarah Doherty, *(IGAC Core Project Office)*, Anne Douglass *(NASA Goddard)*, Veronika Eyring *(DLR)*, Andrew Gettelman *(NCAR-ACD)*, Claire Granier *(Service d'Aeronomie CNRS)*, Didier Hauglustaine *(LSCE, CEA-CNRS)*, Peter Hess *(NCAR-ACD)*, Kathy Hibbard *(AIMES Core Project Office)*, Larry Horowitz *(NOAA-GFDL)*, Ivar Isaksen *(Univ. Oslo)*, Jean Francois (J.F.) Lamarque, *(NCAR-ACD)*, Phil Rasch *(NCAR-ACD & IGAC co-chair)*, A. R. Ravishankara, *(NOAA-ESRL & SPARC co-chair)*, Michael Schulz *(LSCE, CEA-CNRS-IPSL)*, Ted Shepherd *(University of Toronto)*, Drew Shindell *(NASA-Goddard)*

1st AC&C Workshop Attendees:
Yves Balkanski, Gufran Beig, Isabelle Bey, Bill Brune, Philip Cameron-Smith, Mian Chin, Martyn Chipperfield, Bill Collins, Frank Dentener , Sarah Doherty, Veronika Eyring, Arlene Fiore, Savitri Garavait, Claire Granier, Volker Grewe, Ann Henderson-Sellers, Peter Hess, Hans-Werner Jacobi, Terry Keating, Jean Francois Lamarque, Kathy Law, Mark Lawrence, Hong Liao, Jennifer Logan, Tatsuya Nagashima, Thanos Nenes, David Parrish, Vincent-Henri Peuch, Joyce Penner, David Plummer, Michael Prather, Phil Rasch, Sebastian Rast, A. R. Ravishankara, Andreas Richter, Jose Rodriguez, Vladimir Ryabinin, Martin Schultz, Drew Shindell, David Stevenson, Kengo Sudo, Christiane Textor, Michiel van Weele, Oliver Wild, André Zuber.

The SPARC DynVar Project: A SPARC Project on the Dynamics and Variability of the Coupled Stratosphere-Troposphere System

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Introduction

In light of the growing need to understand the global climate system and its future evolution, stratospheric science requires a renewed and sustained research focus. Although we have known for some time that the tropospheric circulation influences the stratosphere, we have more recently learned that the stratosphere can in turn influence the tropospheric circulation all the way to the surface. This two-way stratosphere-troposphere coupling implies that the stratosphere can significantly influence the global climate system and the pattern and magnitude of global climate change. The problem of stratospheric ozone depletion has already demonstrated how human activity can affect a critical component of the global climate system, how a systematic international research effort is required to understand and solve a global environmental problem, how this research needs to be communicated to society, and how ongoing scientific assessment is essential to evaluate the effectiveness of solutions to the problem. All this makes clear that the stratosphere is an integral part of the climate-change problem and will continue to be a crucial component of research on climate change science, impacts, and mitigation.

The two-way coupling we have referred to involves dynamical links between the stratospheric circulation and the tropospheric circulation. The troposphere affects the stratosphere principally through upward propagating atmospheric waves that originate in the troposphere. Until recently it was widely thought that the story ended there, *i.e.* that the stratosphere had little influence on the troposphere. One consequence of this line of thought is that the current generation of global general circulation models (GCMs) typically represent the stratosphere relatively poorly. But several recent lines of research suggest that the stratosphere can in fact significantly influence the tropospheric circulation. The seminal modelling studies of Boville (1984) and Boville and Cheng (1988) demonstrated that degrading stratospheric representation can degrade the simulation of tropospheric stationary waves and transient eddies. Further observational work has developed the view that stratospheric influence involves eddy mean-flow interactions that act on intra-seasonal time scales (Kuroda and Kodera, 1999; Baldwin and Dunkerton, 2001). The cumulative effect of the intra-seasonal time scale coupling leads to a sensitivity of the tropospheric circulation response to stratospheric processes in both the greenhouse-warming and the ozone-depletion problems (Shindell *et al*., 1999; Thompson and Solomon, 2002; Gillett and Thompson, 2003). From the cited studies, and many others, we conclude that improvements to stratospheric representation in models might lead to improvements in seasonal and climate time scale prediction, and ultimately to improvements in the scientific understanding of climate. Characterising and quantifying this kind of stratospheric influence on the troposphere, and ultimately on the global climate system, is a key part of the WCRP SPARC programme.

The goal of this Dynamics and Variability Project for SPARC (which we will refer to by the abbreviation "DynVar") is to approach the question of the dynamical influence of the stratosphere on the troposphere in a systematic way. The principal tools for this effort will be atmospheric general circulation models (AGCMs) with good stratospheric representation. A novel aspect of DynVar is that we will include ocean models coupled to these AGCMs to investigate in a more realistic setting the two-way troposphere-stratosphere coupling. In addition, DynVar will include a significant component devoted to the use of simplified models and more theoretical approaches to build our understanding of stratosphere-troposphere coupling. Here, we outline a modelling and analysis project intended to take place over a period of five years or longer. Previous successful SPARC projects have built collaborative groups around pragmatic and focused plans. With this history in mind, we will propose activities (GCM simulations and diagnostic analyses) that will mesh well with ongoing international projects and with current activities at the modelling centres that are participating in DynVar.

Project Goals

Our 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. We present a representative list of thematic and more specific research questions of interest to us:

1. How does the stratosphere (more specifically, the stratospheric general circulation as represented in climate models) affect the tropospheric general circulation?

- To what extent, and in what way, does a poor representation of the stratosphere degrade the simulation of tropospheric circulation in GCMs?
- What are the consequences of the "fixes" tropospheric modellers need to make (*e.g.* roof/Rayleigh drag) to obtain a reasonable tropospheric climate in their atmospheric GCMs (AGCMs)? To what extent are the model stratospheres sensitive to their treatment of unresolved (*e.g.* gravity) waves and other dissipative processes, and how does this affect the tropospheric simulation?
- How would stratospheric influences on the troposphere affect the simulation of the coupled ocean-atmosphere system?

2. How does the stratosphere influence climate variability on all time scales?

- How well do models capture the intra-seasonal vertical coupling between stratosphere and troposphere in the extra-tropics? Does this coupling influence lower tropospheric variability and the variability of the ocean/sea-ice system?
- Does the stratosphere influence the tropospheric tropical and extra-tropical response to ENSO?
- What are the implications of stratosphere-troposphere coupling for long-range predictions of weather and for forecasts of circulation anomalies on seasonal time scales?
- How does the quasi-biennial oscillation (QBO) affect tropospheric climate?
- How do 11-year solar cycle variations affect tropospheric climate? (In collaboration with SPARC SOLARIS.)

3. How does the stratosphere influence climate change?

- Do models predict in a consistent manner how stratospheric climate change will affect the tropospheric circulation and the coupled ocean-atmosphere system?
- How is the circulation response to climate forcing related to the stratosphere-controlled aspects of climate variability raised in the previous set of questions? For example, do stratosphere-troposphere interactions help explain dynamically the downward influence of Southern-Hemisphere ozone depletion on the tropospheric circulation? And are stratospheric dynamical processes required to explain tropospheric circulation trends over the 20th century?

To address these and related questions, we propose to focus this group's efforts on the analysis of AGCMs with a good representation of the stratosphere. A high-quality stratospheric component includes enhanced vertical resolution and a higher model lid than found in standard climate model simulations, and appropriately configured radiative transfer modules and subgrid scale parameterizations, *etc*. We call these models "high-top", as opposed to standard "low-top" (Boville and Cheng, 1988) climate models with a relatively poor representation of the stratosphere. We describe a set of requirements for the high-top models later in the section entitled "AGCM Requirements" below.

Within the set of stratosphere-resolving AGCMs, we also propose to focus on high-top AGCMs with prescribed radiatively active gases, as opposed to stratosphere-resolving coupled chemistry models (CCMs). The interactive chemistry modules in CCMs increase the computational cost of the models, which constrains the length, resolution, and number of ensemble realizations of the simulations that some groups might commit to. But we will of course not exclude those groups who wish to only run their models with interactive chemistry, provided their models satisfy the minimum requirements as outlined in the section entitled "AGCM Requirements" below.

As well as addressing our research questions, DynVar is meant to help inform and guide the introduction of stratospheric components into comprehensive Earth System Models as these are developed. The high-top/low-top comparison should help us determine to what extent a resolved stratosphere is important for climate-change simulations for future international climate assessments such as the IPCC assessments.

We plan to set up DynVar as an intercomparison activity, with a balanced effort on simulation design and analysis tasks. Fortunately, several members of our group have extensive experience in this kind of effort through the SPARC GRIPS, SPARC CCMVal, and CLIVAR "Climate of the 20th Century" (C20C) projects, as well as through the WMO ozone assessments and the IPCC climate assessments. We will take advantage of existing CCM simulations and AGCM simulations from the ongoing CCMVal and C20C projects (see the section entitled "Connections to Other Projects").

Beyond performing and analysing simulations with comprehensive GCMs, DynVar will also have an important component that focuses on developing a dynamical understanding of stratospheric influence. This component will use simplified AGCMs and theoretical approaches to provide a dynamical perspective on the results of the comprehensive models. It is hoped that this component will strengthen the interactions between the modelling and theoretical approaches.

Project Organization

Paul Kushner is the SPARC DynVar project coordinator, and the co-authors of this newsletter form the project's organizing group. DynVar is divided into four general themes, or "Analysis Areas", under which specific research studies ("subprojects") will be placed. Each analysis area has a coordinator who will act as a contact point for participants, help organize model output release requests, organize workshop sessions, take the lead on summary reports, *etc*. The four analysis areas, which will be described more fully in the next section, are

A. "DynVar Top" (Coordinators: F. Sassi and M. Giorgetta)
B. "DynVar Intraseasonal" (Coordinator: J. Perlwitz)
C. "DynVar Climate Change" (Coordinator: E. Manzini)
D. "DynVar Ideal" (Coordinator: L. Polvani)

Table 1 lists researchers who, in addition to the organizing group, have expressed interest in participating in DynVar. The project's membership is open; if you are interested in participating, please contact

Thomas Birner	U. of Toronto
Andrew Charlton	Reading U.
Bo Christiansen	DMI
Judah Cohen	AER
Eugene Cordero	San Jose State U.
Veronika Eyring (SPARC CCMVal liason)	DLR Oberpfaffenhofen
John Fyfe	CCCma/U. of Victoria
Nathan Gillett	CRU/U. of East Anglia
Lesley Gray (SPARC SOLARIS liason)	Reading U.
Nili Harnik	Tel Aviv U.
Daniel Kirk-Davidoff	U. of Maryland
Kuni Kodera (SPARC SOLARIS liason)	Nagoya U.
Craig Long	NOAA/CPC
Steven Pawson	NASA/GSFC
Thomas Reichler	U. of Utah
David Rind	NASA/GISS
Adam Scaife (CLIVAR C20C liason)	UKMO
Kiyotaka Shibata	MRI Japan
Michael Sigmond	CCCma/U. of Victoria
Seok-woo Son	Columbia U.
David Thompson	Colorado State U.
Darryn Waugh	Johns Hopkins U.
Shigeo Yoden	Kyoto U.

Table 1: Additional Participants

SPARC DynVar *via* the project website: **www.sparcdynvar.org** (click on the email link to contact DynVar).

It is understood that some participants will wish to use the DynVar Project simulations to support their work in other international projects (*e.g*. SPARC CCMVal, SPARC SOLARIS, CLIVAR C20C, or one of the IPCC AR4 assessment subprojects); in this case it will not be necessary for participants to define a new subproject specific to DynVar, but merely to make a clear link to the other project. It is also understood that DynVar participants who wish to study similar topics independently will not be expected to collaborate with each other, but will be expected to communicate with each other through the Analysis Area coordinators.

Keys to success of DynVar include ensuring that the effort be open, transparent and not too burdensome for participating modelling groups; that the simulations be carefully planned and the right model output saved; and that the analyses be straightforward and reproducible so that they can be repeated as new simulations become available. Fortunately, our efforts will be made simpler by following the lead of two other successful WCRP projects: SPARC CCMVal and CLIVAR C20C.

DynVar Analysis Areas

We will now describe in more detail the Analysis Areas, which are mainly meant to break DynVar into manageable pieces. We will work with DynVar participants to identify the appropriate Analysis Area for their specific subprojects, but we recognize that typical subprojects will have elements that belong to more than one area.

Analysis Area A: "DynVar Top" (Coordinators: F. Sassi and M. Giorgetta)

Analysis Area A 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). Subprojects in this theme will compare high-top and low-top climate models run with a variety of degrees of interaction with the ocean, from prescribed sea-surface temperature (SST) models to models with a dynamical ocean component.

Analysis Area A subprojects that have been proposed to date include: an analysis of the influence of enhanced stratospheric representation on the mean circulation, ENSO teleconnections, and low-frequency variability in the troposphere; a study of stratospheric influences on the stationary wave field; a study on the role of planetary wave reflection in determining tropospheric wave structure; and a study on the importance of momentum-conservation constraints in gravity wave drag parameterizations on the coupled stratosphere-troposphere system.

Analysis Area B: "DynVar Intraseasonal" (Coordinator: J. Perlwitz)

Analysis Area B addresses issues of stratosphere-troposphere coupling on intra-seasonal time scales (time scales of 10–100 days). This theme will focus on high-top simulations of stratospheric sudden warmings, annular mode propagation signals, stratosphere-troposphere interactions forced from the surface, and so on. The emphasis will be on dynamical analysis of the stratosphere-troposphere interactions present in these models and on the implications for the practical problem of seasonal prediction.

Analysis Area B subprojects that have been proposed to date include diagnosis of stratospheric sudden warmings and their tropospheric signatures, analysis of the transient response to snow forcing, and a study of the coupling between the North Atlantic Oscillation and the lower stratospheric circulation.

Analysis Area C: "DynVar Climate Change" (Coordinator: E. Manzini)

Analysis Area C addresses the role of the stratosphere in controlling the tropospheric circulation response to climate change, and the implications of this for oceanic and cryospheric climate change responses. Our experience to date has shown that the stratosphere will have a relatively small direct influence on global climate sensitivity (measured formally in terms of the equilibrated response to doubled CO_2); instead, the stratospheric influences here will involve links between radiative forcing and the stratosphere-troposphere circulation.

Analysis Area C subprojects that have been proposed to date include studies of the stratospheric influence on Southern Hemisphere annular mode responses to climate forcing and on sea-ice responses to climate change.

Analysis Area D: "DynVar Ideal" (Coordinator: L. Polvani)

Analysis Area D is the component of SPARC DynVar mentioned above that uses simplified models and more theoretical approaches to improve the dynamical understanding of stratospheric influences. Analysis Areas A–C focus on specific physical phenomena such as the mean stratosphere-troposphere climate, intra-seasonal variability, and climate change responses in the comprehensive AGCM simulations that are the main focus of SPARC DynVar. Analysis Area D, on the other hand, will focus on using complimentary methodologies to elucidate the results of the comprehensive AGCMs. We will encourage Analysis Area D participants to develop research subprojects that aim to explain and characterise the robustness of the comprehensive model results from Analysis Areas A–C.

Analysis Area D subprojects that have been proposed to date include studies of stratospheric control on the time scales of tropospheric variability, of surface-forced stratosphere-troposphere interactions, and of principal modes of variability of the potential vorticity distribution in the stratosphere and troposphere.

Having identified general research themes, we now describe the primary model data sets that, contingent on broad participation from the modelling community, will form the core resource for this activity. We first describe a set of minimum requirements that models should satisfy to represent the stratosphere-troposphere circulation accurately and in a statistically robust way. We then outline our current proposal for a sequence of simulations designed to address our research questions and themes.

AGCM Requirements

Model resolution and configuration: It is important that the high-top models involved in this effort be of sufficient resolution to capture the important dynamics of the large-scale stratosphere-troposphere circulation, particularly in the extra-tropics. At a minimum, these models should be able to resolve baroclinic eddies in the troposphere, Rossby-wave breaking in the stratospheric surf zone, and the vertical structure of extra-tropical planetary-scale waves propagating from the troposphere to the stratosphere, and stratospheric sudden warming events. *Thus the "high-top" models in the DynVar Project should be AGCMs that solve the primitive equations or the non-hydrostatic equations on the sphere, with a horizontal resolution that corresponds to at least T42 (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.* Given the relatively low horizontal resolutions considered, the high-top models should also include parameterizations of the gravity wave influence on the large scale atmospheric circulation.

In setting these requirements, we have attempted to weigh the need to realistically represent some of the most important stratosphere-troposphere interactions against the need to encourage broad participation from modelling groups in DynVar. We recognize that if only these minimum requirements are met, some aspects of stratospheric dynamics and stratospheric influence on the troposphere, for example those that need a realistic simulation of the response to solar forcing or of the vertical structure of planetary-scale tropical waves, might not be well represented.

Some DynVar participants plan to develop methods to systematically transition from low- to high-top AGCMs as a means of introducing stratospheric processes in a controlled manner. This is a potentially valuable approach but will not be required for interested groups to participate in the low-top/high-top comparison. For the low-top models, the main requirement will be that the models have at least T42 horizontal resolution.

Finally, we note that some DynVar participants are planning to investigate the role of the QBO in tropospheric climate but for the time being QBO representation has not entered into our minimum requirements.

Length of simulations (statistical sampling): In some important regions of the stratosphere, particularly in the Northern Hemisphere polar stratosphere, the signal-to-noise ratio of the stratospheric response to climate change is expected to be small (*e.g.* Butchart *et al.* 2000, Fomichev *et al.* 2007). The signals of stratospheric influence on the tropospheric response to climate might consequently be expected to be even more subtle. Thus, we will need to aim for multiple realizations of multi-decadal simulations to ensure meaningful statistical sampling. This requirement will need to be balanced against those of spatial resolution. Factoring in the need for multi-decadal simulations and multiple realizations, the simulations listed below will require at a minimum 50 years of simulation time and often 100 or more years of simulation time.

Boundary and radiative forcings: We will try to implement the boundary and radiative forcings used in the models in as consistent a manner as possible. In this effort we will follow the lead of the CCMVal and C20C projects, which have striven for consistency without placing undue burdens on participating modelling centres.

Proposed Simulations

We propose a sequence of simulations that will help elucidate the effects of stratospheric representation in the absence of coupling to the ocean (AGCM + prescribed SSTs, Simulation Set A), in the presence of thermal coupling to the ocean (AGCM + slab mixed-layer ocean, Simulation Set B), and in the presence of full dynamical coupling to the ocean circulation (AGCM coupled to ocean general circulation model, Simulation Set C).

Set A: "C20C Simulations" -- AGCM simulation with historical SSTs and forcings

The ongoing CLIVAR C20C project (**http://www.iges.org/c20c/**) is studying climate variations over the past 130 years using AGCMs forced with prescribed SSTs and observed radiative forcing. Some modelling groups are already running high-top versions of the C20C simulations. We propose that the SPARC DynVar Project should play a prominent role in examining stratospheric influences for the C20C project, and will encourage participating stratospheric modelling groups to run their own C20C simulations. We also propose that the C20C setup should represent the "workhorse" simulation that represents the initial primary focus of the group.

We propose to compare low-top and high-top versions of the focus period of the C20C simulations that begins in the late 1940's. These simulations will be used to answer many of our research questions related to Analysis Areas A and B. For example, they will help determine the direct influence of representation of the stratosphere on the simulated climate and climate variability. They will also afford us the opportunity to examine the causes of biases in the stratospheric simulation throughout the suite of participating models, which may well affect the character of the stratosphere-troposphere coupling. Trends that are present in the C20C simulations will begin to address the climate change questions of Analysis Area C. It is hoped that at least three realizations of each simulation will be carried out. This will require roughly 150 simulation years for each of the high- and low-top models.

It should be stated that many groups are not prepared to run with the comprehensive list of forcings specified by the C20C. (The forcing prescriptions for the C20C project are available online at **http://www.iges.org/c20c/c20c_forcing/home.html** and include prescriptions for sea-surface temperatures, sea ice, stratospheric volcanic aerosols, carbon dioxide, and ozone.) This will not be a barrier to participation, as long as whatever forcings are used are implemented consistently and are well documented.

Set B: Coupled AGCM/slab mixed-layer ocean model simulations

We have raised a variety of issues related to the influence of the stratosphere on the coupled atmosphere-ocean-cryosphere system. We propose to separately investigate this question using configurations in which an AGCM is coupled to a mixed-layer ocean model (Simulation Set B) and in which an AGCM is coupled to a dynamical ocean model (Simulation Set C). At this point, some groups are focusing their efforts on the mixed layer ocean model approach and others on the dynamical ocean model approach. It is hoped that SPARC DynVar will stimulate groups to pursue both approaches.

For Simulation Set B, participating groups will be asked to run low-top and high-top versions of their coupled models out to equilibrium, which typically takes 50–100 years. Simulations with radiative forcing components representing present day or preindustrial atmospheric composition will be used to address issues related to Analysis Areas A and B. To investigate Analysis Area C, the response to climate change, we propose to use similar simulations in which CO_2 is doubled.

Set C: Coupled AGCM/dynamical ocean model simulations

Finally, we propose to examine the influence of coupling to a dynamical ocean model, building on the Set A and Set B simulations. Several groups are now putting together stratosphere-resolving coupled ocean atmosphere models, and it is hoped that this project will allow these models to be analysed in a coordinated way.

Similarly to the simulations described above, we will encourage modelling groups to contribute model output from high- and low-top versions of their coupled ocean atmosphere models as these are developed. As they come online, we will take advantage of available control simulations with time-independent forcing to address various issues in Analysis Areas A and B, and climate-change simulations to address Analysis Area C. Proposals being discussed at this point for climate change simulations include using the forcing scenarios from the IPCC AR4, or using the simpler 1%/year CO_2 increase forcing from the Coupled Model Intercomparison Project 2 (CMIP2, see **http://www-pcmdi.llnl.gov/projects/cmip/index.php**).

Connections to Other Projects

Connections to the SPARC CCMVal Project (Liason: V. Eyring): A key focus for CCMVal is the evaluation of processes that determine the basic dynamical state of the stratosphere in the underlying GCMs on which the CCMs are based and the response of the stratospheric Brewer Dobson circulation (BDC) to climate change. There is a natural overlap here with DynVar because planetary-scale wave and gravity wave forcing drive much of the BDC overturning. CCMVal is already well established; ongoing diagnostic efforts with existing multi-CCM simulations will certainly help clearly define and begin to answer many of the questions we have raised. In turn, DynVar will support CCMVal with studies to understand statistical uncertainties and to identify robust diagnostics. Thus, the two projects have several points of contact and we can expect mutual benefits for both projects.

Connections to the SPARC SOLARIS Project (Liasons: L. Gray and K. Kodera): The aims of SOLARIS are very specific to understanding the influence of solar variability on both the stratosphere and the troposphere, compared to the aims of DynVar which are much broader. Nevertheless, several of the possible mechanisms for solar influence on the troposphere are identical to those studied in DynVar, so there will be significant potential collaborations, both in terms of simulations and diagnostics.

Connections to the CLIVAR C20C Project (Liason: A. Scaife): C20C has involved the use of both ocean-forced AGCMs and observed data, to study climate variations and changes over the last 130 years, in particular the period since the late 1940's. The analysis subprojects comprising this effort provide an observationally based testing ground for GCMs and Earth Systems Models as they evolve. The standard Set A C20C historical-forcing simulations are carried out fairly routinely at some centres and can provide data that addresses several of our research questions. Several modelling groups, some of whom are already participating in C20C, are planning to improve stratospheric representation or have done so already. Overall the goals and plans of the C20C project mesh well in several respects with those of DynVar.

Conclusion

Many aspects of the SPARC DynVar Project are still in the planning stage. We are at this point identifying interested participants and their subprojects, and identifying modelling groups that are prepared to contribute model output to DynVar. We will next proceed to work with the modelling groups on issues of simulation design and will establish a method of data distribution. Discussion and details of DynVar will take place *via* email and the website being built at **www.sparcdynvar.org**. We will provide updates on the project's progress at the CCMVal meeting in June 2007, at the SPARC SSG meeting in September 2007, and through brief SPARC Newsletter contributions. We plan to report scientific progress on DynVar at the Chapman Conference on stratosphere-troposphere coupling in September 2007 and at the SPARC General Assembly in 2008, and plan to organize focus workshops in the coming year.

In their 1988 study, Boville and Cheng remarked that the "vertical truncation in current GCMs appears to be based primarily on related justifications which are of purely practical origin." The situation remains much the same today, as does the onus on stratospheric scientists to demonstrate to the broader climate community that improved stratospheric representation will improve Earth System Models and will modify the simulated response to climate change. Our sense is that improving stratospheric representation is a tractable task and one that might provide valuable benefits to Earth System Models at a reasonable and predictable cost.

References

Baldwin, M.P. and T.J. Dunkerton, 2001: Stratospheric harbingers of anomalous weather regimes, *Science,* 244, 581-584.

Boville, B. A., 1984: The influence of the polar night jet on the tropospheric circulation in a GCM. *J. Atmos. Sci.*, 41, 1132-1142.

Boville, B. A., and X. Cheng, 1988: Upper boundary effects in a general circulation model, *J. Atmos. Sci*., 45, 2591–2606.

Butchart, N., J. Austin, J. R. Knight, A. A. Scaife and M. L. Gallani, 2000: The response of the stratospheric climate to projected changes in the concentrations of well-mixed greenhouse gases from 1992 to 2051. J. *Atmos. Sci.*, 13, 2142-2159.

Fomichev, V. I., A. I. Jonsson, J. de Grandpre, S. R. Beagley, C. McLandress, K. Semeniuk and T. G. Shepherd, 2007: Response of the middle atmosphere to CO_2 doubling: results from the Canadian middle atmosphere model. *J. Climate*, 20, 1121-1144.

Gillett, N, and D. W. J. Thompson, 2003: Simulation of recent Southern Hemisphere climate change. *Science*, 302, 273-275.

Kuroda, Y. and K. Kodera, 1999: Role of planetary waves in the stratosphere-troposphere coupled variability in the northern hemisphere winter, *Geophys. Res. Lett*., 26, 2375-2378

Shindell, D.T., R.L. Miller, G.A. Schmidt, and L. Pandolfo, 1999: Simulation of recent northern winter climate trends by greenhouse-gas forcing. *Nature*, 399, 452-455, doi:10.1038/20905.

Thompson, D. W. J., and S. Solomon, 2002: Interpretation of recent Southern Hemisphere climate change. *Science*, 296, 895-899.

A SPARC Tropopause Initiative

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Introduction/Goal

SPARC has, since its inception, tried to stimulate research into the dynamics, transport and chemistry in the Upper Troposphere/Lower Stratosphere (UTLS) region. One success has been the organization of several multidisciplinary workshops on this topic, starting with the influential Cambridge workshop in 1993 that resulted in the seminal review by Holton *et al.* (1995). Given the present SPARC emphases of dynamical coupling, detection and attribution, and chemistry-climate modelling, it is appropriate now to examine what SPARC activities promoting the science of the UTLS might be most useful. The intention of this paper is to stimulate discussion about what directions might be most useful, and encourage interested scientists to join that discussion.

This article is not intended as a comprehensive review of tropopause science or literature (and, for example, many key papers have no doubt been left out of the reference list). Our goal is to identify key science questions and gaps in understanding. We have taken account of previously published reviews on this topic, plus recent developments, including the output of recent workshops (most sponsored in part by SPARC). We have also received useful input from several scientific colleagues, many of whom have been involved in planning these workshops.

The UTLS region, or equivalently, the tropopause region, has been identified as being of key importance for chemistry and climate. The Tropical Tropopause Layer (TTL), sets the chemical boundary conditions for the stratosphere. The radiative balance of the TTL, including clouds, is important for the global energy balance. The extra-tropical tropopause layer (ExTL) or extra-tropical UTLS, regulates the ozone budget of the extra-tropical UTLS with potential important impacts on chemistry down to the surface. Dynamical coupling between the troposphere and stratosphere may be modulated in an important fashion by the tropopause region, and this will affect stratospheric dynamics and polar ozone chemistry, as well as surface climate, particularly at high latitudes where dynamical forcing is strong. Whilst most of the above statements are widely accepted, few of them can be made with absolute certainty and fewer still can be made quantitatively precise. Furthermore, it is unclear what horizontal and vertical resolutions, or what representations of small-scale processes are required for these effects to be captured correctly in global climate or chemistry-climate models. Thus, there is a lot of work remaining to be done.

This is an exciting time for tropopause research. We have unprecedented satellite coverage of the UTLS with an international constellation of satellites. The community also has extensive resources for sampling the tropopause *in-situ* from both aircraft and balloon platforms, and there have been many recent campaigns, particularly in the tropics, the results from which are still being analysed and interpreted. New global modelling tools with coupled chemistry are now available to simulate the region.

Our analysis can be summarized in a few key points:

- Recently there have been significant advancements made in understanding the TTL structure, in analysing stratosphere-troposphere coupling at high latitudes and representations of extra-tropical stratosphere-troposphere exchange (STE). However, the dominant processes on various time scales are uncertain, so we cannot reliably predict the future evolution of the TTL, nor, for that matter, the future evolution of different measures of STE.

- There are still interesting and fundamental questions about the maintenance of the extra-tropical tropopause. For instance, what are the respective roles of large-scale mixing processes *versus* moist convective processes? The most appropriate definition of the tropopause poleward of the subtropical jet may be thermal, dynamical or chemical, depending on the processes examined. The relationships between these various definitions are not fully understood. Coupling of chemistry and the extra-tropical tropopause structure is also not well understood.

- We are starting to assess the impact of climate change on the tropopause. There has been less progress or work on looking at the impact of the tropopause on climate. Coupled chemistry climate models and new observations are likely to be critical tools.

- There is a need to assess and collect work on the tropopause region, and to assist researchers in networking and tracking the evolution of ideas and tools (data and models). This is an opportunity for SPARC to advance tropopause science with a 'SPARC Tropopause Initiative'.

Below we describe recent meetings and observations, detail key science topics and key questions, and propose some steps forward, inviting participation from the community. Key acronyms are provided at the end of the document.

Recent Workshops and Field Campaigns

There have been several focused workshops over the last 5-6 years focusing on different aspects of the tropopause, most of them in some way supported by SPARC. Many of these workshops have already been reported on in these pages, so we will be brief in summarizing and providing links to these reports. Further information is available on the web (**http://www.acd.ucar.edu/sparctrop**). Here we briefly refer to three.

In April 2001, there was a wide ranging discussion of tropopause issues in Bad Tölz, Germany. The meeting is summarized in SPARC Newsletter No. 17. There was much discussion of the tropical tropopause as a layer, rather than as a surface, and on the processes that govern water vapour transport into the stratosphere. There was also discussion about mechanisms for and climatologies of Stratosphere-Troposphere Exchange in the extra-tropics. There was some discussion of the extra-tropical tropopause as a transition layer, and the detailed structure of this region, including a recently noted peak in static stability. Theories for the height of the extra-tropical tropopause were also discussed.

In May 2005, a combined SPARC/IGAC workshop focusing on dynamical (transport and mixing) and chemical (photochemistry and microphysics) processes in the UTLS was held in Mainz, Germany. The results of this workshop are discussed in SPARC Newsletter No. 26. Dynamical processes influence tracer distributions in the UTLS and chemical tracer distributions affect the dynamical structure of the ExTL through radiation. There was discussion of short-lived species important in the UTLS. The workshop concluded that a much better understanding had evolved of the climatology of two way STE based on global constraints and detailed case studies.

In June 2006, a joint SPARC/GEWEX/IGAC workshop on the TTL was held in Victoria, Canada. A report appears in SPARC Newsletter No. 28. The workshop tried to engage both the GEWEX and IGAC communities, focusing on the use of cloud resolving models (CRMs) to address TTL issues. There is still a great deal of uncertainty regarding the role of convection and cloud microphysics in the TTL, which is not well constrained for either cloud resolving or global models. Most of the CRM community has not been concerned with the TTL so far, and it is envisaged that the use of such modelling tools would benefit understanding of the TTL. On the other hand, the usefulness of CRMs is potentially limited by the difficulties of representing strong two-way interactions between convecting and non-convecting regions in the tropics with limited area models.

Several other workshops in the 1990s and recently were seminal for advancing the state of understanding of the tropopause. The 1993 workshop on Stratosphere-Troposphere Exchange (SPARC Newsletter No. 2) led to the review paper by Holton *et al*., (1995). The Pointe-du-Lac workshop in 1995 brought together a broad group of dynamicists, chemists, modellers and observationalists to discuss future research priorities (SPARC Newsletter No. 6). The 2003 Giens workshop on chemistry and climate (SPARC Newsletter No. 21 and IGAC Newsletter No. 30) led to the creation of the Atmospheric Chemistry and Climate (AC&C) project.

Recent Observations

Many of the questions noted above and detailed below have been subjects of focused *in-situ* campaigns from various platforms, as well as motivation for satellite instruments. Below we provide a brief and not entirely comprehensive list. We hope to get community input to complete the list with links to the data in the future. More details are available at **http://www.acd.ucar.edu/sparctrop**.

In the last 10 years or so there have been significant field campaigns focused on the tropopause in both the tropics and extra-tropics. Acronyms are provided in an appendix. Multi-platform campaigns with *in-situ* aircraft have been performed in the Indian Ocean (TRACAS, 1998 and APE-THESEO, 1999), the Caribbean (CRYSTAL-FACE, 2002), Brazil (TROCCINOX, 2004), West Africa (SCOUTO3-AMMA, 2006), and a series of campaigns from Darwin, Australia (EMERALD2 2002, ACTIVE/SCOUTO3 and TWP-ICE 2006) and San Jose, Costa Rica (AVE 2004-2006 and TC4 2007). Ongoing *in-situ* campaigns over many seasons have also been conducted from Europe (SPURT), the North Atlantic (STREAM), and globally with commercial aircraft (MOZAIC). In addition, balloon campaigns in the tropics have been conducted with radiosondes and hygrometers (SOWER), ozonesondes (SHADOZ), and long-duration balloons (HIBISCUS). Two new, long-duration, high-altitude research aircraft are in or nearing service in the USA (HIAPER) and Germany (HALO).

New satellites have also started collecting data in the last few years. These platforms include the major European satellites (ENVISAT, METOP) and the series of international satellites in the NASA Earth Observation System (EOS) constellation (Terra, Aqua, Aura, Cloudsat, CALIPSO). These platforms host instruments that are providing unprecedented satellite measurements of the UTLS region. Measured species include temperature (GPS, AIRS, IASI), water vapour (Aura, Envisat, AIRS, IASI) ozone (OSIRIS) and other chemical tracers from carbon monoxide (AIRS, MLS, IASI), N_2O, to isotopes of water and suites of shorted lived halocarbons (ACE). We also now are just starting to get more detailed measurements of UTLS clouds, aerosols and ice microphysics from space from traditional limb (MLS) or infrared measurements (MODIS, AIRS) to active radars (CloudSat) and Lidars (CALIPSO).

All these observations have started to answer some of our questions, but have also raised new ones that we detail below.

Science Topics

General Questions

There are some basic current questions regarding the tropopause that cover both the tropics and extra-tropics. Probably the most obvious is the question: *how might the tropopause change in response to climate change* (*i.e*. the radiative forcing of the Earth system from anthropogenic activities)? Modelling studies (Santer *et al.*, 2003) show that it might change, but there is no real theory that predicts such changes. There is a lack of certainty on the key processes that might change the tropopause. We are only beginning to disentangle the relevant dynamical, radiative and thermodynamical processes in both the tropics and the extra-tropics. The lack of understanding is particularly severe in the extra-tropics. Furthermore, defining how the tropopause might change may be sensitive to how the tropopause is defined, and below we note several different approaches for the tropics and extra-tropics.

The converse question is: *what is the role of the tropopause and UTLS in climate change*? Ozone and water vapour are important greenhouse gases, and important for the radiation balance of the UTLS and tropospheric climate. Stratospheric water vapour has an impact on tropospheric climate (Forster and Shine, 2002). Many climate models ignore the stratosphere, and represent the tropopause with relatively coarse resolution. Yet the sign of future tropospheric ozone changes appears to be sensitive to the description of STE (Stevenson *et al*., 2006). Ozone and water vapour in the UTLS are best thought of as 'feedbacks': ozone and water vapour are perturbed by changes in transport, thermodynamics and chemistry, and through radiation, may affect them in return. These feedbacks are not well understood. Several studies have recently looked at how a change in trace species such as ozone or water vapour will affect the radiative budget and thermal structure of the TTL or the UTLS (Gettelman *et al*., 2004, Randel *et al*., 2006), but the impacts of changes to the thermal structure are not yet clear. We do not know how STE or the Brewer Dobson circulation will change, the latter of course strongly affects both the tropics (upwelling region) and the extra-tropics (downwelling region), though recent model studies suggest that the Brewer Dobson circulation will increase (Butchart *et al*., 2006). Moist convection in the tropics affects the tropopause, but the tropopause also helps set the environment for tropical moist convection.

Many of the results above, and in particular projections of future changes, are derived from models. *To what extent are important tropopause processes captured by global chemical-climate models?* There are now a series of fully coupled global general circulation models. 'Coupled' implies that they contain chemical transformations of radiatively active species that interact and affect model heating rates (Eyring *et al*., 2006). Yet, chemical-climate model studies of the tropopause are few. The UTLS may be the next big challenge (after ozone recovery) for chemical-climate models. There are many important fine scale features observed in the tropopause region, such as clouds, small scale waves, large thermodynamic gradients and nonlinear chemical mixing. *How important are these fine scale features to the large-scale structure of the tropopause region? What are the implications of them not being captured in large scale models? Does this invalidate the basic conclusions (including future trends) from the simulations?* These questions are critical for assessing uncertainty over future projections of climate and ozone levels affected by the UTLS.

The subtropical barrier between the tropics and the extra-tropics, defined by the mid-latitude jets and a change in height and character of the tropopause, is a complex region that is not well studied. While there have been several studies of quasi-horizontal transport between the TTL and the extra-tropical lowermost stratosphere (Chen 1995, Stohl *et al*., 2003), the importance for both the tropics and extra-tropics is uncertain. Subtropical UTLS water vapour may also be an important part of the subtropical radiation budget. There is longstanding work on the distribution of transport, but less work on how this affects transport or structure in each region.

Tropical Tropopause Layer (TTL)

In the last 5-10 years the tropical tropopause has come to be known as the Tropical Tropopause Layer (TTL). The tropical tropopause is not a material surface, and is best thought of as a layer several kilometers thick within which air may have elements of both the stratosphere and troposphere. The idea is not new (Atticks and Robinson, 1983), but has been developed further recently (Highwood and Hoskins, 1998, Folkins, 1999, Gettelman and Forster, 2002). While this paradigm has achieved some consensus, there is still a great deal of discussion of basic process questions.

What determines the tropical tropopause (cold point) temperature? This is critical for understanding water vapour transport in and through the TTL, which as noted affects stratospheric chemistry and tropospheric climate. The climatology of the cold point temperatures is now well documented, including the annual cycle (Seidel *et al*., 2001), interannual variability (Zhou *et al*., 2001a, 2001b; Randel *et al*., 2004), and geographic variability and zonal asymmetries. However, recent studies of both large scale (Fujiwara *et al*., 2003) and small scale (Randel *et al*., 2003, Vincent and Alexander, 2000) variability show a huge range of scales. These include small scale forcing by convective clouds and waves resulting from clouds, to the ultimate drivers such as sea surface temperatures. The relative roles of local and global processes in forcing the annual cycle of mean temperatures are not fully understood (Kerr-Munslow and Norton, 2006) and this throws doubt on the idea that temperatures on longer time scales are largely controlled by the strength of the wave-driven Brewer Dobson circulation. Given this lack of understanding, it is not surprising that we cannot fully understand inter-annual variability of tropical tropopause temperatures (and the TTL in general). We understand some aspects of variability from sea surface temperatures and modes like ENSO (Gettelman *et al.*, 2001; Zhou *et al*., 2001a) and the QBO (Zhou *et al*., 2001a, Giorgetta *et al*., 1999, Geller *et al*., 2002). But (for example), we cannot fully explain the recent cold event (from 1999 onwards) at the tropical tropopause, which limits our ability to predict how the tropical tropopause will change over time given forcing from changes in ozone and other greenhouse gases. Changes may occur through direct radiative effects, radiative-convective effects or indirect dynamical effects (through changes to the Brewer Dobson circulation).

What controls transport in the TTL and how do chemical species get from the surface into the stratosphere? Up to the level of the main convective outflow (10-12 km), transport is dominated by circulations forced by convective latent heating and clear sky cooling. Above 15 km, radiative heating and then dynamical forcing from the Brewer Dobson circulation are dominant, but between these levels is a critical region where it is not known whether isolated and infrequent convection, or some other wave driven process, is most important. The role of chemistry in this region, and chemical-radiation-dynamics feedbacks is also not well understood. Observations of the TTL are also sparse, which complicates validation of hypotheses or model results. The role of the tropopause in affecting convection in the TTL and TTL transport is also not well understood. A new picture of clouds in the TTL is rapidly emerging from active cloud sensors on CloudSat and CALIPSO.

Transport is especially important for short-lived species in the TTL such as halogens (that may affect ozone). Important species are also a function of the transport pathways and their geographic variation, as very short-lived or soluble species may not survive transport. One of the key issues for very short-lived species (VSLS), *e.g*. bromine species, is washout (or analogous processes) in the TTL. It is important to know time scales for transport in the TTL to quantify ozone-depletion by VSLS halogens, but the key issue detailed in the 2002 and 2006 ozone assessments (WMO, 2002) is *how are 'product gases' (i.e. inorganics resulting from breakdown of VSLS) removed through moist processes*? This requires a better understanding of the different roles of convective and non-convective transport in the TTL.

Extra-tropical UTLS

There is still quite a bit of discussion over the basic definition of the extra-tropical tropopause and the ExTL around it. Understanding the ExTL is important to characterize ozone transport, which is important for chemistry and climate. The ExTL is also important for understanding the dynamical coupling between the stratosphere and troposphere, which may add to the predictability of the tropospheric circulation. The basic issues have to do with definitions, structure, transport and chemistry.

The ExTL is a vertical and horizontal transport barrier and also a region of strong gradients with a thickness. In this region, dynamics is at least as important as chemistry. Generally, the extra-tropical tropopause can be defined *thermally* (lapse rate tropopause), *dynamically* as a surface of potential vorticity (Haynes and McIntyre, 1987) or a gradient of a dynamical quantity like effective diffusivity (Haynes and Shuckburgh, 2000), or *chemically* using the gradient of ozone, carbon monoxide and/or water vapour (Pan *et al*., 2004). Recently there has been more attention paid to chemical definitions. *Does the definition of the extra-tropical tropopause (chemical, thermal, dynamical) and ExTL matter, and why?* The appropriate definition of the extra-tropical tropopause or extra-tropical tropopause region may depend on the problem. For example, defining a tropopause to track long-term dynamical changes may be very different than defining one to assess the transport of ozone from the stratosphere into the troposphere. Each of these definitions may imply some thickness to the ExTL region. And it is not clear that there is a unique set of relationships between the thermal, dynamic and the chemical definitions of the extra-tropical tropopause.

These competing definitions and perspectives complicate the understanding of basic processes, but also provide a number of different approaches towards understanding the basic question of *what governs the structure of the extra-tropical UTLS*? The relative role of small-scale processes (convection/breaking gravity waves) *vs*. large-scale baroclinic disturbances (synoptic-scale eddies/conveyor belts) *vs*. the overturning stratospheric circulation is not yet clear. Particular regions, such as the Asian Monsoon, may contribute disproportionately to the global structure. Recent work has highlighted the existence of a peak in stability above the tropopause (Birner, 2006), co-located with large chemical gradients. *What processes determine this stability peak and stability in general at the small scale?* We don't really know what physical processes lead to the static stability maximum and, correspondingly, we don't know whether there is any relation between the region of enhanced static stability and the transition layer seen in chemical species. This complex structure influences tracer distributions across the tropopause, and radiatively active species may affect the thermal structure of the ExTL. These feedbacks are not well understood. In high latitudes the feedbacks may affect coupling between the stratosphere and troposphere.

A great deal has been learned about STE since the review of Holton *et al*., (1995), but big issues of transport in the ExTL remain. Uncertainty remains regarding the net exchange of species across the tropopause, though we now have a better understanding of where the transport occurs (Stohl *et al*., 2003). There are still conceptual barriers for upscaling from individual events (tropopause folds, convective or pyro-convective injections of mass into the stratosphere), and small scale events (convection) are not well sampled. We are now starting to relate climatologies of STE to distributions of key UTLS tracers such as ozone, carbon monoxide and water vapour from satellites.

Key questions

These issues can be distilled into several sets of key questions and paths forward. There are three key classes of questions in both the tropics and extra-tropics: (1) basic questions of structure of the TTL and ExTL, (2) questions related to global change and interactions between the tropopause and forcings of the system, and (3) chemical interactions that maintain or modify the structure of the tropopause.

1.1 How do we explain variations in the tropical cold-point tropopause temperatures on annual-decadal scales?
1.2 What are the respective roles of radiation and dynamics in determining tropopause structure?
1.3 What are the roles of baroclinic eddies and convection on the formation and maintenance of the extra-tropical tropopause?
1.4 Can we better understand how different definitions of the ExTL relate to each other?

2.1 How might we expect tropopause structure to vary with a changing climate and ozone distribution?
2.2 What would be the feedback on climate of a changing tropopause?
2.3 How is tropopause an indicator of global change?

3.1 How does tropopause region affect stratosphere and tropospheric chemistry?
3.2 What are the interactions between chemistry and tropopause structure?
3.3 What is the role and fate of short-lived species in UTLS chemistry?

We now have a unique set of observations to attack some these questions. Accordingly, since these data are new, we have certainly not exploited the current set of *in-situ* and satellite observations to the full. *Where are observations needed in the UTLS both for understanding (a) small-scale transport (convection, microphysics), and for assessing (b) long term trends at a 'climate' scale?* The latter question (b) is particularly acute. We have many individual field campaigns, and many different satellite instruments, but what measurements are needed in order to monitor changes in the chemical composition and the dynamical structure of the tropopause region now and into the future? These questions deserve some hard thinking now to plan future observations and manage current ones.

Finally, with our analysis and modelling tools, we are also only beginning to exploit coupled global chemistry and climate models in the UTLS. These models are built upon many years of separate development of chemistry packages (as chemical transport models) and general circulation (climate) models. Putting them together allows us to understand the chemical and dynamical couplings described above. But coupled models are very hard to diagnose, and exploring the differences between models, and between models and observations in the UTLS will be a challenge and an opportunity. Furthermore, there are questions of resolution that are particularly acute for resolving sharp gradients at the tropopause. To what extent does smoothing of these sharp gradients with relatively coarse resolution affect transport?

What can SPARC do?

The themes above are several, and we summarize them here: In the tropics, understanding what drives tropical tropopause temperatures and how they will evolve in the future is critical for global chemistry and climate. Cloud microphysics and aerosol-cloud interactions are also important. In the extra-tropics, there is a need to further develop and understand thermal, dynamic and chemical approaches to the ExTL structure and how they relate to each other. In both regions there has been some work on how the tropopause region might be affected by climate changes and be an indicator of climate change, but less work on how the tropopause region may affect climate. Combined with this, understanding interactions between chemistry and the structure of the tropopause region will lead to a more complete understanding of UTLS chemistry climate coupling. We have new modelling tools and observations at our disposal to answer these questions.

A unique aspect of the current state of tropopause science, which is clear from the questions above, is that the answers require interactions between groups and communities that have not worked closely together in the past. The mutual interaction of convection with the TTL, involving cloud researchers with stratospheric chemists, is one example. Coupling the dynamics and chemistry of the ExTL is another. Given the numerous and sometimes disparate programmes involved in studying the TTL, and the breadth of expertise required to answer these questions, there are clearly things that can be done to encourage and foster critical tropopause research. SPARC is already working in these areas: there is a big SPARC investment in chemistry-climate modelling through CCMVal and, in association with IGAC, in the AC&C project.

Deciding on SPARC actions in these areas is made difficult by the large number of open issues. Clearly, workshops for all of them would be ill-advised. There might, however, be a small number of issues that would benefit from a workshop energizing a small community to make progress. We propose as a start that SPARC should track tropopause science, discussing key science questions and promoting education of young (and old) scientists on different aspects of tropopause science. Such a function could provide a valuable resource for education: tracking papers and meetings, promoting and archiving focused schools on the tropopause, and promoting attendance of young scientists at key meetings. This community might also highlight areas where having small workshops will accelerate scientific progress.

The SPARC tropopause community could also do more to foster community plans for future observations. This might include (1) critical remaining regions for field programmes, especially in regions where we might be able to involve typically under-represented groups (such as the Asian summer monsoon) and (2) ensuring our capacity to measure the UTLS on climate scales (*e.g.* stratospheric ozone and water vapour, reference networks for the tropopause).

We invite interested scientists to get involved in this nascent SPARC tropopause 'initiative'. Challenge us on what we have written, prove us and the conventional wisdom wrong, and bring new analyses, observations and models to the table. We have established a home at **http://www.acd.ucar.edu/sparctrop**, where we will expand on these ideas, track research and track meetings. This initiative can fill in gaps in research while encouraging interactions and participation of young scientists and those from under-represented regions. Please join us to help develop the initiative.

Acronyms:

ACE:Atmospheric Chemistry Experiment (Canadian SciSat)
ACTIVE: Aerosol and chemical transport in tropical convection
AIRS: Atmospheric Infrared Sounder
AMMA: African Monsoon Multidisciplinary Analyses
APE-THESEO: Airborne Platform for Earth observation- Third European Stratospheric Experiment on Ozone
AVE: Aura Validation Experiment
CCMVal: Chemistry Climate Model Validation project
CALIPSO: Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation
CRYSTAL-FACE: The Cirrus Regional Study of Tropical Anvils and Cirrus Layers - Florida Area Cirrus Experiment
EMERALD: Egrett Microphysics Experiment, with Radiation, Lidar and Dynamics
ENVISAT: Environmental Satellite
ENSO: El Niño Southern Oscillation
EOS: Earth Observation System
ExTL: Extra-tropical Tropopause Layer
GEWEX: Global Energy and Water cycle Experiment
GPS: Global Positioning System

HALO: High Altitude and LOng Range Research Aircraft
HIBISCUS: Impact of tropical convection on the upper troposphere and lower stratosphere at global scale
HIAPER: High-performance Instrumented Airborne Platform for Environmental Research
IASI: Infrared Atmospheric Sounding Interferometer
IGAC: International Global Atmospheric Chemistry
MLS: Microwave Limb Sounder
MODIS: Moderate Resolution Imaging Spectroradiometer
MOZAIC: Measurements of OZone and water vapour by in-service AIrbus airCraft
OSIRIS: Optical Spectrograph and Infrared Imaging System (on ODIN)
QBO: Quasi Biennial Oscillation
SCOUTO3: Stratospheric-Climate Links with Emphasis on the Upper Troposphere and Lower Stratosphere
SHADOZ: Southern Hemisphere Additional Ozonesondes
SOWER: Soundings of Ozone and Water in the Equatorial Region
SPARC: Stratospheric Processes and Their Role in Climate
SPURT: Spurenstofftransport in der Tropopausenregion (Transport in the Tropopause Region)
STE: Stratosphere Troposphere Exchange
STREAM: Stratosphere-Troposphere Experiments by Aircraft Measurements
TC4: Tropical Clouds Chemistry Climate Coupling experiment
TRACAS: TRAnsport of Chemical species Across the Subtropical tropopause
TROCCINOX: Tropical Convection, Cirrus, and Nitrogen Oxides Experiment
TTL: Tropical Tropopause Layer
TWP-ICE: Tropical Warm Pool International Cloud Experiment
UTLS: Upper Troposphere and Lower Stratosphere
WMO: World Meteorological Organization

References

Atticks, M. G. and G. D. Robinson, 1983: Some features of the structure of the tropical tropopause. *Q. J. R. Meteorol. Soc*., 109 (460), 295–308.

Birner, T., 2006: Fine-scale structure of the extratropical tropopause region. *J. Geophys. Res*., 111, doi:10.1029/2005JD006301.

Butchart, N., A. A. Scaife, M. Bourqui, J. de Grandpre, S. H. E. Hare, J. Kettleborough, U. Langematz, E. Manzini, F. Sassi, K. Shibata, D. Shindell, and M. Sigmond, 2006: Simulations of anthropogenic change in the strength of the Brewer-Dobson circulation. *Clim. Dynamics*, 27, 727–741, doi:10.1007/s00382-006-0162-4.

Chen, P., 1995: Isentropic cross-tropopause mass exchange in the extratropics. *J. Geophys. Res.*, 100 (D8), 16,661–16,673.

Eyring, V. *et al*., 2006: Assessment of temperature, trace species, and ozone in chemistry-climate model simulations of the recent past. *J. Geophys. Res*., 111 (D22308), doi: 10.1029/2006JD007327.

Folkins, I., M. Loewenstein, J. Podolske, S. J. Oltmans, and M. Proffitt, 1999: A barrier to vertical mixing at 14 km in the tropics: Evidence from ozonesondes and aircraft measurements. *J. Geophys. Res*., 104 (D18), 22,095–22,102.

Forster, P. M. d. F. and K. P. Shine, 2002: Assessing the climate impact of trends in stratospheric water vapor. *Geophys. Res. Lett*., 29 (6), 10.1029/2001GL013 909.

Fujiwara, M., M. K. Yamamoto, H. Hashiguchi, T. Horinouchi, and S. Fukao, 2003: Turbulence at the tropopause due to breaking Kelvin waves observed by the Equatorial Atmosphere Radar. *Geophys. Res. Lett*., 30 (4), doi:10.1029/2002GL016278, 1171.

Geller, M. A., X. Zhou, and H. Zhang, 2002: Simulations of the interannual variability of stratosphereic water vapour. *J. Atmos. Sci*., 59, 1076-1085.

Gettelman, A. and P. M. F. Forster, 2002: A climatology of the tropical tropopause layer. *J. Met. Soc. Japan*, 80 (4B), 911–924.

Gettelman, A., P. M. F. Forster, M. Fujuwara, Q. Fu, H. Vomel, L. K. Gohar, C. Johanson, and M. Ammerman, 2004: The radiation balance of the tropical tropopause layer. *J. Geophys. Res*., 109, doi:10.1029/2003JD004190.

Gettelman, A., W. J. Randel, S. Massie, F. Wu, W. G. Read, and J. M. Russell III, 2001: El-Nino as a natural experiment for studying the tropical tropopause region. *J. Clim*., 14, 3375–3392.

Giorgetta, M. A. and L. Bengtsson, 1999: Potential role of the quasi-biennial oscillation in the stratosphere-troposphere exchange as found in water vapor in general circulation model experiments. *J. Geophys. Res*., 104 (D6), 6003–6019.

Haynes, P. and M. E. McIntyre, 1987: On the evolution of vorticity and potential vorticity in the presence of diabatic heating and frictional or other forces. *J. Atmos. Sci*., 44 (5), 828–841.

Haynes, P. and E. Shuckburgh, 2000: Effective diffusivity as a diagnostic of atmospheric transport 2. Troposphere and lower stratosphere. *J. Geophys. Res*., 105, 22 795–22 810, doi: 10.1029/2000JD900092.

Highwood, E. J. and B. J. Hoskins, 1998: The tropical tropopause. *Q. J. R. Meteorol. Soc*., 124 (549), 1579–1604.

Holton, J. R., P. H. Haynes, A. R. Douglass, R. B. Rood, and L. Pfister, 1995: Stratosphere–troposphere exchange. *Rev. Geophys*., 33 (4), 403–439.

Kerr-Munslow, A. M. and W. A. Norton, 2006: Tropical wave driving of the annual cycle in tropical tropopause temperatures. Part I: ECMWF analyses. *J. Atmos. Sci*., 63, 1410–1419.

Pan, L. L., W. J. Randel, B. L. Gary, M. J. Mahoney, and E. J. Hintsa, 2004: Definitions and sharpness of the extratropical tropopause: A trace gas perspective. *J. Geophys. Res*., 109 (D23103), doi:10.1029/2004JD004982.

Randel, W. J., F. Wu, S. J. Oltmans, K. Rosenlof, and G. E. Nedoluha, 2004: Interannual changes of stratospheric water vapor and correlations with tropical tropopause temperatures. *J. Atmos. Sci*., 61, 2133–2148.

Randel, W. J., F. Wu, and W. R. Rios, 2003: Thermal variability of the tropical tropopause region derived from GPS/MET observations. *J. Geophys. Res*., 108 (D1), ACL 7, doi:10.1029/2002JD002595.

Santer, B. D., M. F. Wehner, T. M. L. Wigley, R. Sausen, G. A. Meehl, K. E. Taylor, C. Ammann, J. Arblaster, W. M. Washington, J. S. Boyle, and W. Bruggemann, 2003: Contributions of anthropogenic and natural forcing to recent tropopause height changes. *Science*, 301, 479–483, doi:10.1126/science.1084123.

Seidel, D. J., R. J. Ross, J. K. Angell, and G. C. Reid, 2001: Climatological characteristics of the tropical tropopause as revealed by radiosondes. *J. Geophys. Res.*, 106, 7857–7878.

Stevenson, D. S. *et al*., 2006: Multimodel ensemble simulations of present-day and near-future tropospheric ozone. *J. Geophys. Res*., 111 (D08301), doi:10.1029/2005JD006338.

Stohl, A. *et al*., 2003: Stratosphere-troposphere exchange: A review, and what we have learned from STACCATO. *J. Geophys. Res*., 108 (D12), doi:10.1029/2002JD002490.

Vincent, R. A. and M. J. Alexander, 2000: Gravity waves in the tropical lower stratosphere: An observational study of seasonal and interannual variability. *J. Geophys. Res.*, 105, 17 971–17 982, doi:10.1029/2000JD900196.

Zhou, X., M. A. Geller, and M. Zhang, 2001a: Tropical cold point tropopause characteristics derived from ECMWF reanalysis and soundings. *J. Climate,* 14, 1823-1838.

Zhou, X., M. A. Geller, and M. Zhang, 2001b: The cooling trend of the tropical cold point tropopause temperatures and its impliations. *J. Geophys. Res*., 106 (D2), 1511–1522.

Key issues arising from the 2006 WMO/UNEP Ozone Assessment

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In the 2002 Assessment it was indicated that the total atmospheric burden of ozone-depleting substances was responding as expected to the controls on production imposed by the Montreal Protocol, and that "the ozone-layer depletion from the Protocol's controlled substances is expected to begin to ameliorate within the next decade or so". The Executive Summary of the 2006 Assessment noted that "an important next step is to ask whether stratospheric ozone and surface UV radiation are responding as expected to the controls imposed by the Protocol. In addressing this question it is necessary to consider factors other than ozone-depleting substances that also influence ozone and UV radiation. These factors include natural dynamical variability, volcanic eruptions, solar variations, aerosols, and climate change." The status of our understanding and the key questions for several of these issues are discussed below.

Ozone-depleting substances: The observed tropospheric abundances of HCFCs are increasing more slowly than anticipated, and those of bromine-containing gases are declining more quickly than anticipated. While both facts are good for the ozone layer, it is important to reconcile them with estimates of the relevant emissions. The importance of stratospheric bromine from very short-lived species (VSLS) appears to be significantly greater than previously estimated (WMO, Figures 2–3), and needs to be better quantified. We are still waiting for the observed decline of tropospheric bromine to be reflected in the stratosphere.

Tropical ozone trends: Observations of column ozone from both ground-based and satellite data show no significant trends in the tropics (25°S – 25°N) for 1979-2005. However, trends in the profile of ozone measured by satellite show significant negative trends in the tropical upper stratosphere (from SAGE and SBUV data), and SAGE data furthermore suggest relatively large percentage decreases in the tropical lower stratosphere (**Figure 1a)**. The vertical integral of the profile trends is significantly larger than the observed column ozone changes (**Figure 1b**). These differences could be reconciled by corresponding increases in tropical tropospheric ozone (with a net ~15% increase over 1979-2005), or it may be that the profile trends are overestimates for some reason. There is particular uncertainty for the changes in the lower stratosphere, where satellite measurements are difficult, and there are not independent observations of long-term changes.

Short-term ozone recovery: Ozone depletion has levelled off in every region of the atmosphere, consistent with the levelling off of stratospheric EESC (equivalent effective stratospheric chlorine). In some regions, ozone abundance has increased notably in the last 5 years or so (for example, over NH midlatitudes below 20 km; WMO Figures 3-11). This cannot yet be considered ozone recovery (since EESC has not notably declined), and the reasons for these increases need to be better understood since such variations will confound the detection of the onset of ozone recovery.

Polar ozone and PSC microphysics: There is now unambiguous evidence from Arctic measurements that NAT (nitric acid trihydrate) polar stratospheric cloud (PSC) particles can nucleate above the ice frost point, and that their occurrence can be widespread. Incorporating this process in chemical transport models (CTMs) improves the simulation of denitrification in the Arctic, but discrepancies remain in properly representing the effects of interannual variability, pointing to an incomplete understanding. Moreover, many of the specifics of PSC formation, such as freezing rates, remain empirical. Without a reliable representation of PSC processes, CCM predictions of past and future polar (especially Arctic) ozone are significantly compromised.

Volcanoes: The impact of the Mount Pinatubo volcanic eruption on stratospheric ozone remains something of a puzzle. While ozone amounts declined sharply in the Northern Hemisphere (NH) following

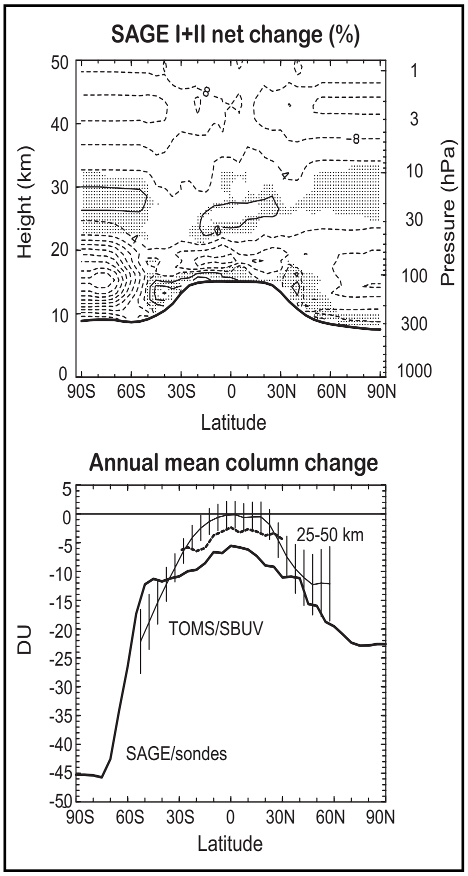

Figure 1. (a) Meridional cross section of ozone trends during 1979-2005 derived from SAGE satellite and polar ozone-sonde data. Trends are derived from regression onto EESC, and expressed in terms of net percentage change during 1979-2005. Contours are -4, -8, -12, -16, -20, -30, -40%. (b) Latitudinal structure of annual mean column ozone trends during 1979-2005, derived from vertically integrated SAGE/sonde data and merged TOMS/SBUV data. Trends are expressed in terms of net ozone change over 1979-2005. The heavy dashed line denotes trends derived from SAGE data, integrated only over 25-50 km. From Randel and Wu, 2007.

the eruption, no such decline was evident in the Southern Hemisphere. Moreover, a number of modelling studies have suggested that the NH decline was mainly associated with changes in transport. As there are likely to be one or more volcanic eruptions during the ozone recovery period, there is a need to better understand the likely impact of such an eruption on stratospheric ozone.

Stratospheric temperature trends: There are substantial improvements in understanding the uncertainties in historical stratospheric temperature data sets. The long-standing differences between lower stratospheric trends derived from Microwave Sounding Unit (MSU) satellite data and radiosonde-based results can be reconciled by recognizing cooling biases in many individual radiosonde stations (associated with instrumentation improvements over time). Omitting the stations with largest biases allows more accurate estimates of past variability and change (**Figure 2**). There is also improved understanding of satellite data in the middle and upper stratosphere (from the Stratospheric Sounding Unit, SSU), including quantifying the effects of increasing CO_2 on the measurements (which can significantly influence trend results). These improved observational data sets will provide critical tests for simulations of past stratospheric changes.

Dynamical variability: Long-term variability in wave forcing and other dynamical quantities appears to have had a significant effect on observed ozone abundance, especially in the NH, and has the potential to affect ozone recovery on both short and long time scales. It is therefore important to understand the extent to which long-term variability in dynamics may be associated with climate change, and to better understand causes of natural variability (including the apparent "trends" associated with decadal-scale variability). **Figure 3** shows the observational record of winter-average planetary wave forcing of the NH stratosphere for 1979-2006, together with winter average polar stratospheric temperatures. These data show significant interannual variability across a range of scales (yearly to decadal); the fundamental causes of such variability, and potential shifts in a changing climate, are poorly understood.

Tropical tropopause temperature and water vapour: CCMs generally predict a warming of the tropical tropopause region from climate change, and a modest increase in stratospheric water vapour, but these predictions do not appear to be consistent with past observations. CCM simulations of both fields often show large biases, with significant differences among models (Eyring *et al*., 2006, Figure 7). It is possible that long-term changes predicted in the models are more robust, but this would need to be demonstrated. There are also remaining uncertainties regarding decadal-scale changes in the observational record.

Brewer Dobson circulation and age of air: CCMs suggest an increase in tropical upwelling and thus decrease in age of air throughout the stratosphere, due to climate change (WMO, Figures 5-19). The extent of the increase varies substantially among models. The mechanism for the increased upwelling has yet to be determined, and its robustness assessed. Changes in age of air call into question the ODS scenarios used by CCMs, which impose tropospheric concentrations and thus cannot represent the effects of a faster removal of ODSs.

Solar signal in ozone: The ozone solar signal provides a key physical link between solar variability and climate, and is also important for interpreting low frequency ozone variability. However, there are substantial uncertainties in quantifying effects of the 11-year solar cycle on stratospheric ozone and temperature, both in comparisons of models and observations, and even among different observational data sets. The main differences regard the magnitude of the solar signal in column ozone (**Figure 4**), and the vertical profile of the solar signal in the tropics; much of the uncertainties result from the relatively short observational data records, and possible confusion of volcanic and QBO effects.

Ozone simulation by CTMs: When driven by observed meteorology, CTMs should, in principle, be able to reproduce the observed behaviour of ozone. This makes CTMs potentially useful tools for separating (to the extent this is possible) the effects of chemi-

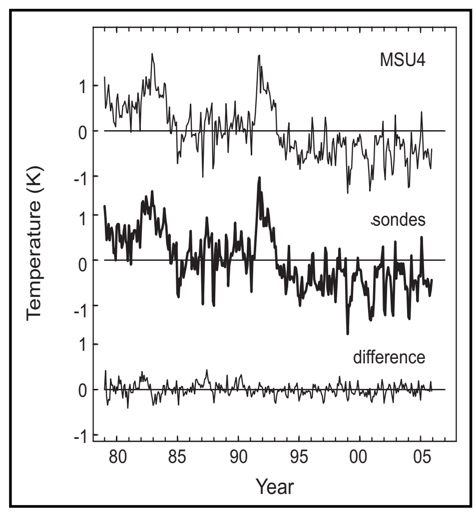

Figure 2. Comparison of near-global deseasonalized temperature anomalies calculated from MSU4 satellite data (top), vertically-integrated radiosonde data (middle), and their difference (bottom). MSU4 represents a weighted mean of temperatures in the layer ~13-22 km. The radiosonde results are averages over 35 individual stations over 60°N-S, using a subset of the Lanzante-Klein-Seidel data set (Lanzante et al. 2003), and are vertically weighted using the MSU4 weighting function. The MSU4 data here have been sampled at these same 35 station locations.

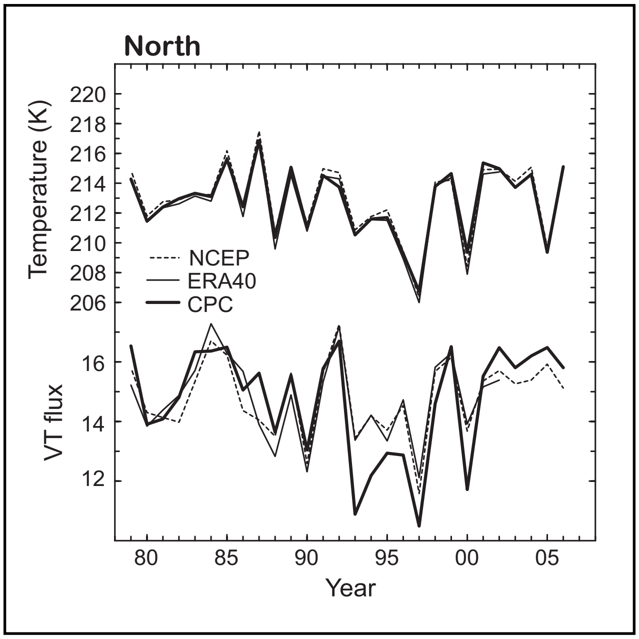

Figure 3. Lower time series show winter-averaged eddy heat flux (a proxy for planetary wave forcing) at 100 hPa for the NH for 1979-2006 (averaged over December-March for each year). Upper curves show the corresponding January-March averaged polar 100 hPa temperatures (averaged over 60°– 90°N). Both sets of curves show results derived from NCEP and ERA40 reanalyses, plus NCEP Climate Prediction Center (CPC) data.

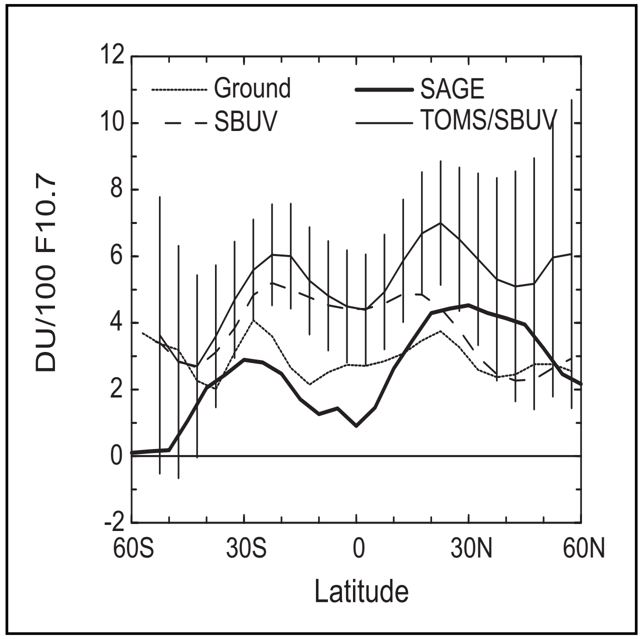

*Figure 4. Latitudinal profile of the solar cycle variations in column ozone, derived from vertically integrated SAGE I+II data (over 20-50 km), and three column ozone data sets (ground-based, SBUV, and merged TOMS/SBUV data). Error bars on the TOMS/SBUV curve denote 2*sigma uncertainty in the fit.*

cal and dynamical processes on observed ozone changes. Although CTMs have been used very successfully to identify chemical processes in the context of particular winters, decadal-timescale simulations by CTMs are still plagued by errors in transport (*e.g.* age of air) from assimilated winds. This limits our ability to attribute past ozone changes.

Ozone simulation by CCMs: CCM predictions of future ozone are limited by a persistent young bias in age of air, although the situation has improved markedly in recent years. CCM simulations of mid-latitude ozone can reproduce the overall features the past record, but there are substantial uncertainties in detail and differences among models (WMO Figures 3-26). While the observational record contains significant effects of dynamical variability, especially in the NH, such variability should also be evident in the CCMs. Reconciling the past observations with CCM simulations remains an essential task.

Polar ozone and long-term recovery: Model predictions of future Arctic ozone are highly uncertain because of large uncertainties in the future dynamical state of the Arctic polar vortex (WMO Figures 6-12, 6-13). It will be important to understand the sensitivity of modelled dynamical behaviour to various model parameters, such as horizontal/vertical resolution, dynamical wave forcing, radiative balances, *etc*. Model simulations need to become more robust and provide better estimates of the uncertainty associated with natural variability, as well as the effects of climate change.

Radiative forcing from ozone changes: The radiative forcing from stratospheric ozone changes (*e.g.* as used by IPCC) assumes that all the ozone changes are due to ODSs and thus that the ozone radiative forcing is an indirect forcing which can be set against the direct radiative forcing from the ODSs themselves. However, it seems clear that a significant fraction of the observed ozone changes are associated with changes in transport rather than with ODSs. Moreover, these transport-induced changes appear to be located preferentially in the lowest part of the stratosphere, where they have a maximum impact on radiative forcing. It is thus necessary to quantify the vertical profile of ozone changes attributable to ODSs, and its associated radiative forcing.

References

Eyring, V. *et al*., Assessment of temperature, trace species and ozone in chemistry-climate model simulations of the recent past, *J. Geophys. Res*., 111, D22308, doi:10.1029/2006JD007327, 2006.

Lanzante, J.R., S.A. Klein, D.J. Seidel, 2003: Temporal homogenization of monthly radiosonde temperature data. Part I: Methodology. *J. Climate*, 16, 224-240.

Randel, W. J., and F. Wu (2007), A stratospheric ozone profile data set for 1979–2005: Variability, trends, and comparisons with column ozone data, *J. Geophys. Res.*, 112, D06313, doi:10.1029/2006JD007339.

Scientific Assessment of Ozone Depletion: 2006, *WMO*, Report No. 50.

EOS Aura Mission – Three Years in Orbit

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Introduction

Aura, the last of the large NASA Earth Observing System (EOS) observatories, was launched on July 15, 2004 into an ascending node 705 km sun-synchronous polar orbit with a 98° inclination and an equator-crossing time of 13:45±15 minutes. It has now been operating nearly three years with a design life of five years and an operational goal of six years, although Aura carries enough fuel to last until 2015. Aura is making comprehensive stratospheric and tropospheric composition measurements from its four instruments, High-Resolution Dynamics Limb Sounder (HIRDLS), Microwave Limb Sounder (MLS), Ozone Monitoring Instrument (OMI) and Tropospheric Emission Spectrometer (TES). We report on the status of the Aura mission and summarize recent Aura science results in this article. More Aura science highlights can be found at **http://aura.gsfc.nasa.gov/**.

Aura is part of the afternoon constellation of satellites, the "A-train", flying about 15 minutes behind EOS Aqua (**http://aqua.nasa.gov/**, launched in 2002), a platform focused on measurements important to the Earth's hydrological cycle, aerosols and other variables important to Earth system science and climate change. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO, **http://www-calipso.larc.nasa.gov/**) and CloudSat (**http://cloudsat.atmos.colostate.edu/**) were successfully launched into formation between Aqua and Aura on April 28, 2006. The "A-train" also includes the CNES PARASOL satellite (**http://smsc.cnes.fr/PARASOL/GP_mission.htm**, (launched in 2004), the ESSP Orbiting Carbon Observatory (OCO, **http://oco.jpl.nasa.gov/**), scheduled for launch in 2008, and Glory (**http://glory.gsfc.nasa.gov/**, a climate-monitoring satellite also scheduled for launch in 2008.

The Aura platform

The Aura platform contains four instruments, all of which make measurements of atmospheric composition. The Ozone Monitoring Instrument (OMI), a contribution of the Netherlands's Agency for Aerospace Programs (NIVR) in collaboration with the Finnish Meteorological Institute (FMI), employs hyperspectral imaging in a push-broom mode to observe solar backscatter radiation in the visible and ultraviolet (Levelt *et al*., 2006). OMI continues the Total Ozone Mapping Spectrometer record for total ozone and other atmospheric parameters related to ozone chemistry and climate. OMI is sensitive to absorbing aerosol over both land and sea and can measure cloud pressure. The Tropospheric Emission Spectrometer (TES) is high-resolution infrared-imaging Fourier transform spectrometer (Beer 2006). TES has both limb and nadir observing modes. It is currently operated mainly in the nadir mode to measure tropospheric ozone, carbon monoxide and water vapour. The Microwave Limb Sounder (MLS) uses microwave emission to measure constituents in the stratosphere and upper troposphere, including the ice content and upper tropospheric water vapour in the presence of tropical cirrus (Waters *et al*., 2006). The High Resolution Dynamic Limb Sounder (HIRDLS) is an infrared limb sounder that obtains profiles of temperature, constituents and aerosols (Gille *et al*., 2007). The objectives of the Aura mission and a summary of the observations expected from each of the instruments were described in SPARC Newsletter No. 26 available from **http://www.atmosp.physics.utoronto.ca/SPARC/Newsletters.html**. Details about MLS, OMI and TES and their performance can be found in the May 2006 IEEE *Transactions on Geoscience and Remote Sensing*, a special issue on the Aura Mission.

Current status

All four Aura instruments are operating and returning high quality information about the atmosphere, but there have been some anomalies. The most serious concerns HIRDLS and was encountered during instrument activation about a month after launch. The optical path is partially blocked by a piece of thermal blanketing. Only 20% of the aperture views the Earth's atmosphere, eliminating the possibility of horizontal scans across the orbit path. Optimum strategies for operation of HIRDLS and methods to account for the blockage in retrieval have been developed. High vertical resolution profiles are being obtained at a single scan angle 47° off the orbit plane, away from the sun. Coverage obtained by HIRDLS is limited to 64°S to 80°N. With this limited scan pattern HIRDLS cannot make measurements over the Antarctic.

In June 2005, an increase in the current required to drive the TES translator was detected. The rise in current is attributed to bearing wear in the interferometer control system (ICS). During a limb scan the distance travelled by the translator is much greater than the distance required for a TES nadir observation, so routine operations now emphasize the nadir mode. This change should make it possible for TES to continue observations for the planned six years of the Aura mission.

The primary channel for MLS observations of HCl began to fail in February 2006. This channel is no longer in routine use to preserve lifetime. It is used for occasional global measurements to track the decline of HCl in the upper stratosphere that is expected due to the decline in man-made chlorofluorocarbons in accordance with the Montreal Protocol and its amendments. Daily HCl profiles are still retrieved from MLS using observations in a different channel, but with slightly increased noise.

Science Highlights

The following are a few of the recent scientific accomplishments enabled by Aura observations. For a more comprehensive listing of achievements, see the Aura web site.

HIRDLS observes Mountain Waves

HIRDLS measures temperature profiles in the stratosphere, revealing small-scale atmospheric buoyancy waves that are known as "gravity waves" in fine detail. Breaking gravity waves may be generated by flow over mountains and can cause turbulence felt by aircraft. Although these waves are small in scale and sporadic in occurrence, collectively they drive global-scale winds that affect weather and climate. Dr. Joan Alexander of NorthWest Research Associates, collaborating with Dr. John Gille and his colleagues at the National Center for Atmospheric Research and the University of Colorado, has analysed HIRDLS data to identify the locations and sources of intermittent gravity wave events. The study identifies waves in adjacent HIRDLS temperature profiles, estimates the temperature amplitude and horizontal and vertical wavelengths for each profile pair, and from these estimates maps of momentum flux (Alexander *et al*., 2007).

Two of HIRDLS ascending and descending orbits cross each other at the tip of South America. The temperatures obtained along segments of these two orbits are shown in **Figure 2** (colour plate I) as functions of horizontal distance along the orbit *vs*. altitude. Large-scale mean temperatures have been removed to reveal the waves. The alternating red and blue coloured regions show warm and cold temperature oscillations caused by the mountain waves. West is to the left in both panels. The mountain waves extend through the stratosphere up to about 60 km, into the region known as the mesosphere. The high vertical resolution of the HIRDLS measurements allows researchers to study these waves in fine detail in order to improve parameterizations of wave effects on the general circulation models of the atmosphere.

TES Traces the Earth's Hydrological Cycle

TES measurements of water (H_2O) and the isotope 'heavy' water (HDO) (**Figure 3**, colour plate II) provide clues for tracking the hydrological cycle, the origin and movement of water vapour throughout Earth's atmosphere (Worden *et al*., 2007). Water isotopic abundances can be used to trace the history of an air parcel since lighter isotopes preferentially evaporate while heavier isotopes are more likely to condense. Therefore, enhanced condensation leads to more isotope depletion. The TES measurements show that in the tropics, re-evaporation of precipitation is an important process controlling cloud formation. Up to 70% of precipitation is re-evaporated into the cloud.

The hydrological cycle acts differently in different locations. Over Africa, HDO and H_2O are both high, suggesting rapid recycling of both HDO and H_2O. Over the Indian Ocean, HDO is depleted even though H_2O is high, suggesting that H_2O is removed by precipitation without much re-evaporation. At high latitudes, H_2O and HDO are low, suggesting that air parcels have repeatedly lost HDO through precipitation events.

OMI Sees the Fingerprints of Industry

OMI measures the atmospheric column of ozone, nitrogen dioxide, and sulphur dioxide (SO_2). SO_2 is emitted by volcanoes and is also emitted as a result of some industrial processes. The nominal spatial resolution of OMI measurements is 13 x 24 km in nadir, thereby enabling specific source attribution for the OMI SO_2 observations. Volcanic emissions are identified in **Figure 4** (colour plate III), and can be compared with the sources from copper smelters in Peru. These data provide insights into the different lifetimes and dispersion of volcanic and industrial emissions. Weak SO_2 plumes are seen to be transported off the coast of Ecuador due to the higher altitude and longer lifetime of the volcanic sulfur emissions. Intense emissions are seen from the smelters at La Oroya and Ilo. The pollution at La Oroya is considered to be more serious than that at Ilo even though the Ilo smelter has higher emission values, because of the higher population near La Oroya.

MLS Provides the First Global Measurements of Upper Tropospheric Cloud Ice

MLS observations of vertical profiles of cloud ice, along with collocated measurements of temperature and water vapour, represent a new and important capability. These observations will be used to assess the realism of general circulation models (GCMs) in simulating upper tropospheric ice water content (IWC). Li *et al*. (2005) compare MLS observations with atmospheric analyses from the European Centre for Medium-Range Weather Forecasts and with results from several GCMs as shown in **Figure 5** (colour plate IV). For January 2005 monthly and daily mean values, the patterns produced by MLS and ECMWF are similar, but MLS estimates are higher by a factor of 2-3 over the West Pacific, tropical Africa and South America. The similarity between the GCM and MLS patterns varies. These results are subject to uncertainties associated with sampling, the retrieval technique, and the manner in which the comparisons are made. Thus, they illustrate the need for high-quality observations of cloud-related quantities to evaluate GCM performance and guide future development efforts. These observations, combined with MLS's observations of temperature and water vapour as well as measurements from other NASA EOS "A-Train" platforms – particularly the CloudSat mission – provide the opportunity to assess upper-tropospheric hydrological processes and to evaluate and improve the representation of cloud processes in GCMs. Such improvements will reduce uncertainty in climate change predictions.

Validation

Validation of Aura measurements has included an extensive programme to obtain correlative measurements using a variety of instruments from the ground, aircraft, and high altitude balloons. Instruments such as ACE on the Canadian Sci-Sat, and Aura's overlap with the Upper Atmosphere Research Satellite and EP TOMS were important. A series of satellite science and validation campaigns using NASA's airborne science platforms have been conducted over the past three years and will continue for the foreseeable future. The Aura Validation Experiment (AVE) series of field campaigns have been conducted from Houston, TX in Fall 2004 and Summer 2005; from Portsmouth, NH in Winter 2005; and from Costa Rica in Winter 2006. The most extensive field campaign (the Tropical Composition, Cloud, and Climate Coupling, TC4 experiment) will use several NASA airborne platforms operating from Costa Rica in the summer of 2007 to integrate A-Train validation with a suite of chemistry and climate science objectives.

Further details of these and other missions that have played a role in Aura validation (such as INTEX-NA) can be obtained at **http://www.espo.nasa.gov/**. Several heavy lift balloon campaigns focused on Aura validation have been conducted from Ft. Sumner, NM and Kiruna, Sweden while numerous balloon-sonde launches at many locations around the globe have provided correlative data for ozone, water vapour, and meteorological parameters.

Submissions to a special issue of *Journal of Geophysical Research – Atmospheres* are presently in review. We anticipate the Aura validation papers to be published in two special issues, and that the first will appear in late 2007.

Data Release

Aura data are being released through the Langley (TES) **http://eosweb.larc.nasa.gov/PRODOCS/tes/table_tes.html** and Goddard (MLS, OMI, HIRDLS) **http://acdisc.gsfc.nasa.gov/** Distributed Active Archive Centers. Data from all instruments are publicly available. We encourage users to make use of the information about the data quality that is available from the instrument websites and through the refereed literature. We also encourage participation in the Aura science team meetings (next meeting: October 1-5 2007, Pasadena, CA)

Summary

The EOS Aura mission was successfully launched on July 15, 2004. With the exception of HIRDLS, all of the instruments are functioning as designed, although to preserve instrument life, TES is now operating only in the nadir mode. Aura is providing the next level of measurements needed by the stratospheric and tropospheric research communities to address crucial broad questions concerning the recovery of stratospheric ozone, the changing chemical composition of the troposphere and its implications for air quality, and the roles of upper tropospheric aerosols, water vapour and ozone in climate change. The breadth of these instrument capabilities will allow the use of Aura data to attack these and new questions that will be defined in the future.

For more information on the Aura platform and instruments, please refer to the Aura web site **http://aura.gsfc.nasa.gov**.

References

J. Alexander, J. Gille, C. Cavanaugh, M. Coffey, C. Craig, V. Dean, T. Eden, G. Francis, C. Halvorson, J. Hannigan, R. Khosravi, D. Kinneson, H. Lee, S. Massie, B. Nardi, A. Lambert, "Global Estimates of Gravity Wave Momentum Flux from High Resolution Dynamics Limb Sounder (HIRDLS) Observations," submitted to *J. Geophys. Res*., 2007.

R. Beer, "TES on the Aura Mission: Scientific Objectives, Measurements, and Analysis Overview," *Transactions on Geoscience and Remote Sensing*, 44, 1102-1105, 2006.

Carn, S. A., A. J. Krueger, N. A. Krotkov, K. Yang, and P. F. Levelt, "Sulfur dioxide emissions from Peruvian copper smelters detected by the Ozone Monitoring Instrument," *Geophys. Res. Lett.*, 34, L09801, doi:10.1029/2006GL029020, 2007.

J. Gille *et al.*, "The High Resolution Dynamics Limb Sounder (HIRDLS): Experiment Overview, Results and Validation of Initial Temperature Data," submitted to *J. Geophys. Res*., 2007

J.-L. Li *et al*., "Comparisons of EOS MLS Cloud Ice Measurements with ECMWF analyses and GCM Simulations: Initial Results," *Geophys. Res. Lett*. 32, L18710, doi:10.1029/2005GL023788, 2005.

P. F. Levelt, *et al.*, "The Ozone Monitoring Instrument," *Transactions on Geoscience and Remote Sensing*, 44, 1093-1101, 2006.

J. W. Waters *et al*., "The Earth Observing System Microwave Limb Sounder (EOS MLS) on the Aura Satellite, *Transactions on Geoscience and Remote Sensing, 44, 1075-1092, 2006.*

Worden, J., D. Noone, K. Bowman, "Importance of evaporation and continental convection in the tropical water cycle," *Nature*, 445, 428-532, 2006.

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Announcement

Special session of the European Geosciences Union General Assembly 2007
Vienna, Austria, 15 – 20 April 2007
Variability and predictability of the coupled Stratosphere-Troposphere system

A web page has been created by Dr. Andrew Charlton (University of Reading, UK), which contains oral and poster presentations given at the EGU General Assembly 2007 in the session ***Variability and Predictability of the Coupled Stratosphere-Troposphere System (session AS1.06)***. All of the talks are copyright to the authors. Please contact them via the e-mail address link for more details of their work, and to seek permission from the authors before reproducing any of the content, as some of it remains unpublished. Links to the archived presentations from 2006 are also available.

http://www.met.reading.ac.uk/~sws05ajc/egu/

SPARC-IPY Update

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The goal of the SPARC IPY Activity entitled *The Structure and Evolution of the Polar Stratosphere and Mesosphere and Links to the Troposphere during IPY*, (IPY Activity No. 217) is to document the dynamics, chemistry and microphysical processes within the polar vortices during IPY, with a focus on stratosphere-troposphere and stratosphere-mesosphere coupling. One of the key outcomes will be a collection of analysis products from several operational centres and several research centres, which will be archived at the SPARC Data Center.

The analysis products will cover the period of IPY (March 2007 to March 2009) and will represent the best available self-consistent approximations to the state of the atmosphere during this period. Some satellite products will also be available for comparison with the analyses, and we are working on activating links with other IPY activities such as POLARCAT (IPY Activity No. 32), PANSY (IPY Activity No. 9), and ORACLE-O3 (IPY Activity No. 99), and other related activities such as ACCENT. The specialized observations and field campaigns associated with these other activities will complement the data assimilation products and provide validation opportunities. Ensuring that the links with these other activities are established, maintained, and utilized will be the responsibility of Dr. Elham Farahani who has recently been hired as the SPARC-IPY coordination scientist.

The analysis data will be available through the SPARC Data Center. Registration on the web site is required. Data will be available in GRIB and netCDF formats depending on the centre providing the data, and Climate Data Operators (cdo) will be available for quick access of the data, and for conversion to other data formats. The web site is undergoing testing and will be available in the near future. The contributing centres and current status of the data acquisition process are summarized in the table.

Centre/Model	Country	Resolution	Fields	Status
NCEP	USA	0.32x0.32 on 64 levels at 00h, 06h, 12h,18h	u, v, T, specific humidity, ozone, cloud water, p	Receiving data
GMAO	USA	0.67x0.5 on 72 model levels at 00h, 06h, 12h, 18h (water vapour fields at ± 1:30h from analysis)	u, v, T, RH, PV, ozone, Q_ice, Q_liquid, geopotential height, total diabatic tendency, SLP, p, cloud fraction, cloud optical depth	Receiving data
ECMWF	Europe	0.25x0.25 on 91 model levels at 00h, 06h, 12h,18h	u, v, T, divergence, ozone, cloud cover, Q, cloud ice water content, cloud liquid water content	Receiving data
UKMO	UK	0.56x0.38 on 27 pressure levels at 12Z	u, v, T, geopotential height, dz/dt	Receiving data
CMAM-DAS	Canada	3.75x3.68 on 72 model levels to 0.01mb at 00h, 06h, 12h, 18h	u, v, T, SLP, Ox, ozone, ClOx, BrOx, HNO_3, methane, NO, NOx, NO_3, N_2O_5, ClO, $ClONO_2$, BrO, H_2O, specific humidity	Further testing required
GEM-STRATO	Canada	1.5x1.5 on 80 model levels to 1mb at 00h, 06h, 12h, 18h	u, v, T, geopotential height, p, moisture, infrared heating, ozone, methane, N_2O, CO, H_2O, ClO, OClO, $ClONO_2$, HCl, NO, NO_2, N_2O_5, HNO_3	Further testing required
KNMI	Netherlands		Ozone	Pending
HDRI	UK – BADC	1.88x1.88 on 10 isentropic levels at 00h, 04h, 08h, 12h, 16h, 20h	Ozone	Pending

Saroja Polavarapu – SPARC DA representative
Norman McFarlane – Lead SPARC-IPY Contact
Elham Farahani – SPARC-IPY Project coordinator
Diane Pendlebury – SPARC-IPY Data coordinator

Acronyms

PANSY: Program of the Antarctic Syowa MST/IS radar
ORACLE-O3: Ozone layer and UV radiation in a changing climate evaluated during IPY
POLARCAT: Polar Study using Aircraft, Remote Sensing, Surface Measurements and Models, of Climate, Chemistry, Aerosols, and Transport
ACCENT: Atmospheric Composition Change The European Network of Excellence

SPARC 4th General Assemby

31 August - 5 September 2008

WCRP
World Climate Research Programme

CNR Conference Center

Bologna, Italy

Deadline for Abstract Submission: 29 February 2008

SPARC 2008 Web Site: http://www.cmcc.it/sparc-ga2008

Scientific topics will include:

- Stratosphere-Troposphere Dynamical Coupling
- Stratospheric Variability and Climate Change
- Extra-tropical Upper Troposphere/Lower Stratosphere
- Detection, Attribution and Prediction of Stratospheric Change
- Tropical Tropopause Layer
- Atmospheric Chemistry and Climate

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SPARC Office Web Site http://www.atmosp.physics.utoronto.ca/SPARC

Future SPARC and SPARC-related Meetings

2007

20-24 August — **American Meteorological Society 14th Conference on the Middle Atmosphere,** Portland, Oregon, USA (http://www.ametsoc.org/meet/fainst/200715isa14m.html)

27-31 August — **Second International Conference on Earth System Modelling,** Hamburg, Germany (http://www.mpimet.mpg.de/fileadmin/static/icesm/)

29-31 August — **Polar Dynamics: Monitoring, Understanding, and Prediction,** Bergen, Norway (http://web.gfi.uib.no/conference2007/info.htm)

4-7 September — **SPARC Data Assimilation Workshop and SPARC IPY Workshop,** Toronto, Canada (http://www.fields.utoronto.ca/programs/scientific/07-08/data_assim/)

24-28 September — **Chapman Conference: The Role of the Stratosphere in Climate and Climate Change,** Santorini, Greece (http://www.agu.org/meetings/chapman/2007/ccall/)

5-9 November — **SPARC / SCOUT-O3 / NDACC / CNRS Reunion Island International Symposium,** Reunion Island, Saint-Gilles les Bains (http://riis2007.univ-reunion.fr/)

10-14 December — **AGU Fall Meeting**, San Francisco, California, USA http://www.agu.org/meetings/fm07/

2008

13-20 July — **37th Scientific Assembly of the Committee on Space Research and Associated Events - COSPAR 2008 "50th Anniversary Assembly"** Montreal, Canada (http://www.cospar-assembly.org/)

31 August-5 September — **4th SPARC General Assembly;** CNR Conference Center, Bologna, Italy (http://www.cmcc.it/sparc-ga2008) Scientific Committee Co-Chairs: P. Haynes (phh@damtp.cam.ac.uk) and T. Peter (thomas.peter@env.ethz.ch)

*****Deadline for Abstract Submission: 29 February 2008*****

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