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Report on the 17th Session of the SPARC Scientific Steering Group

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The 17th Session of the SPARC Scientific Steering Group (SSG) was held at the University of Kyoto, hosted by SSG member Professor Masato Shiotani. This year the SPARC SSG meeting was held concurrently with the IGAC SSC meeting in the same location. These meetings were immediately preceded by a local workshop, jointly sponsored by the Japanese SPARC and IGAC communities. This workshop was well attended and featured invited and contributed talks from the Japanese and international SPARC and IGAC communities as well as an excellent poster session.

The SPARC and IGAC groups met separately except for a joint day during which issues of common interest were discussed. However, break periods and social events were held in common. This was an effective way to promote interactions between the two groups.

WCRP Update

Following a brief opening session, **V. Ryabinin** and **G. Asrar** presented an update on recent developments and new perspectives within the WCRP and outcomes of the World Climate Conference-3 (WCC-3; see the report on WCC-3 by V. Ryabinin in this Newsletter). The WCRP perspective on planning includes two time periods with different overarching foci. In the next 3-5 years (2010-15), the emphasis will be on implementing the WCRP Strategic Framework (COPES) through the WCRP Implementation Plan for the Core Projects and Panels and Cross-WCRP Initiatives. In the longer term (post 2015 period) a restructuring of the WCRP will likely be required to ensure a continuing effective alignment with the scientific issues of the time and to achieve the long-term goal of more effective interactions with users of climate information products.

Within the past two years substantial effort has gone into developing the WCRP Implementation Plan. The broad aims of this plan are: (a) to outline the major challenges in research on physical components of the climate system: the oceans, cryosphere, water and energy cycle, atmospheric chemistry and dynamics, and the complex interactions within and among them; (b) to list specific activities that will help WCRP to deliver science in support of societal needs; (c) to identify and facilitate new scientific thrusts: decadal predictability, sea-level variability and change, climate extremes, and atmospheric chemistry–climate interactions; and (d) to maintain ongoing areas of investigation: climate change projections, seasonal predictions, monsoons, and polar research.

All of the WCRP Core Projects contribute in varying degrees to some or all of the topics in (c) and (d), which represent the integrating themes of the Implementation Plan. (The SPARC contribution is summarised in Newsletter No. 33 and also posted on the SPARC web site: **http://www.atmosp.physics.utoronto.ca/SPARC/index.html**) While details of the long-term (post 2015) strategy remain to be worked out, the new WCRP functions and structure will be determined to facilitate research on the frontiers of the climate/Earth system and promote the availability and use of science-based climate information, products and services.

An important upcoming event is the WCRP Science Conference 2011, which will have as its main theme "Scientific Knowledge for Climate Adaptation, Mitigation and

Risk Management". The main motivations for holding this conference are to provide input to IPCC AR5, to evaluate progress on implementing COPES, to facilitate the future strategic evolution of the WCRP, to strengthen cross-connections between WCRP activities, and to mark the 30th anniversary of the WCRP. The conference will be comprised of symposia on cross-cutting themes/topics. The likely location will be in the USA. Jim Hurrell (Co-Chair of CLIVAR) has agreed to chair the Scientific Organising Committee.

T. Peter summarised key outcomes of the last WCRP JSC meeting and their importance for future SPARC activities and evolution (see the report on the 30th Session of the JSC in SPARC Newsletter No. 33, July 2009). From a SPARC perspective, the direction for future development of WCRP is seen to be a very positive one, which recognises the value of past WCRP achievements and provides stability for future planning.

SPARC-IGAC Regional Workshop

M. Shiotani presented an overview of the IGAC-SPARC regional workshop. The theme of this workshop was "The One Atmosphere". The workshop was very successful and highlighted the strengths and impressive achievements of the IGAC and SPARC communities in both measurement and modelling. In particular, Japanese modellers are world leaders in the development and use of high-resolution global atmospheric models for a wide range of applications.

Overview of SMILES and PANSY

M. Shiotani also reported on observational data from the Japanese Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) which was designed to be aboard the Japanese Experiment Module on the International Space Station (ISS). SMILES was successfully attached to ISS, and has been performing very well. Comparison with reference data and validation data will enhance the confidence in the retrieval results.

K. Sato reported on the Program of the Antarctic Syowa Mesosphere - Stratosphere - Troposphere (MST) / Incoherent Scatter (IS) Radar (PANSY) for which an operating budget has been approved. This radar will cover the height range from 1 km in the troposphere to 500 km in the ionospheric F region. It has capability of both MST and IS radars to provide observations of three-dimensional winds and plasma parameters such as electron density and plasma (electron and ion) temperatures with fine time and height resolutions. It is expected to enable a wide range of science projects that will elucidate features of Antarctic weather and circulation patterns.

Joint SPARC/IGAC Day

At their joint session the SPARC SSG and IGAC SSC reviewed progress on activities of common interest and explored areas where closer interaction and collaboration is desirable.

Cross-cutting SPARC/IGAC Activities and Issues

CCMVal

V. Eyring presented an overview of the SPARC CCMVal activity. A major focus of CCMVal is supporting the WMO/UNEP Ozone Assessments (2006, 2010) and the IPCC Assessment Reports (AR4, AR5) through coordinated chemistry-climate model (CCM) simulations for the recent past and present, and projections for the remainder of the 21st century, accompanied by a diagnostic evaluation. Output from CCMVal-1 simulations has been collected in the central CCMVal database at the British Atmospheric Data Centre (BADC). Evaluation diagnostics have been obtained from various observational data sets. Currently around 60 CCMVal Collaborators are working with CCMVal output, and numerous CCMVal-1 papers have been published.

Multi-model evaluations have revealed important differences among models and have demonstrated the advantage of a multi-model evaluation strategy, but the results of CCMVal-1 were somewhat unsatisfying from an assessment perspective. This led to an effort to develop quantitative performance metrics. The CCMVal metrics development has come at an opportune time to mesh with other similar efforts within the WCRP and the IPCC. A WGNE/WGCM metrics panel has been established and an IPCC Expert meeting on "Metrics" and "Assessing and Combining Multi-model Climate Projections" will be held in January 2010, at NCAR, Boulder, USA.

CCMVal-2 is now well underway with 18 models participating. The reference time period for the simulations begins earlier (1960) than for CCMVal-1 and most simulations extend throughout the 21st century. The earlier starting date allows a more accurate determination of the milestone when total ozone returns to pre-1980 levels. The extended period of the simulations allows systematic multi-model ozone projections and an analysis of the causes of these projected changes throughout the 21st century.

A major undertaking of CCMVal this year has been the production of the SPARC CCMVal Report on Evaluation of CCMs. The report timelines have been followed with the final review meeting in Toledo, Spain held in November 2009, followed by final revisions in December and a projected publication in the second quarter of 2010. The CCMVal Report will provide critical input to the 2010 Ozone Assessment.

The draft outline for IPCC WG1 AR5 has been prepared and includes a number of entry points for CCMVal and IGAC-SPARC activities. In addition, an interesting entry point of AR5 WG2 may be the combined effects of ozone recovery and climate change on human health.

Atmospheric Chemistry and Climate (AC&C)

The AC&C activity is a cross-cutting initiative between the WCRP and IGBP with IGAC and SPARC having joint responsibility for it. **P. Rasch**, IGAC co-chair of AC&C, reported on the status of this activity. A. Ravishankara has stepped down as the SPARC co-chair and Martyn Chipperfield has replaced him.

Phase I of AC&C involves a number of modelling activities: (1) 20-year hindcast; (2) determination of what controls the vertical distribution of species in the upper troposphere; (3) cloud-chemistry interactions; and (4) sensitivities and uncertainties of future scenarios. Plans were firmed up at the 2nd AC&C workshop held jointly with HTAP in June 2008. From the perspective of IPCC assessments, the paradigm for the Phase 1 activities has been shifted from preparing models for IPCC runs to facilitating, and coordinating some of the model runs relevant to IPCC.

The interface of Phase I hindcast activities with CCMVal is that, for 'whole atmosphere' models, the chemistry needs to build on recent CCMVal REF-B1 simulations (1960-2005). Full chemistry specifications need to include stratospheric forcings and boundary conditions. Other remaining issues include the starting time (CCMVal hindcasts start in 1960 while those with a tropospheric focus start in 1980; in order to harmonise these specifications, tropospheric emissions would need to be prescribed from 1960).

IPCC and CMIP5

The WCRP JSC/CLIVAR Working Group on Coupled Modelling (WGCM) facilitates intercomparison and evaluation of coupled ocean/atmosphere/land models (CGCMs) for climate studies. Because of its close ties to the major modelling groups and centres, WGCM also coordinates CGCM modelling support for the IPCC assessments. SPARC SSG member V. Eyring is also a member of WGCM, which provides a liaison between AC&C, SPARC and WGCM activities.

The GCCM input to IPCC AR5 will be provided in the context of CMIP5. The forcing data sets for CMIP5 (accessible *via* the CMIP web site **http://cmip-pcmdi.llnl.gov**) will include the AC&C / SPARC Ozone Databases that have been constructed to provide a merged tropospheric / stratospheric ozone time series from 1850 to 2100 for use in CMIP5 simulations without interactive chemistry. The future database (2010-2099) utilises a multi-model CCMVal-2 mean for the stratosphere combined with tropospheric ozone projected using the Community Atmosphere Model (CAM) version 3.5

Halogen Chemistry Activity

M. Kurylo summarised the issues that motivated the SPARC Halogen Chemistry Initiative and its major outcomes. The ClOOCl photodissociation cross section has been the largest source of uncertainty in the description of the polar ozone loss chemistry. Recent laboratory measurements fell clearly outside the range of uncertainty defined by prior studies, leading to much debate within the atmospheric chemistry community. A detailed report from a SPARC workshop that was held in Cambridge (June, 2008) is available electronically under **http://www.atmosp.physics.utoronto.ca/SPARC/index.html**. Results of several new laboratory studies (published or about to be published) convincingly show that the previous understanding of chlorine-catalyzed ozone loss in the polar stratosphere was correct. The SPARC Initiative played an important role in fostering this new work.

Laboratory Studies

P. Monks commented on the role and status of laboratory-based studies in atmospheric science and summarised some recent developments. He noted that, although laboratory studies are fundamental to atmospheric science and drive innovation, they are under threat due to the indifference of funding agencies. There is an urgent need to highlight this situation with respect to laboratory work in the international arena.

The EUROCHAMP consortium is an exemplary laboratory collaboration. It links 14 European institutes, each of which possess unique, well equipped, custom-built chambers for studying atmospheric processes. This consortium has integrated existing chambers into a Europe-wide infrastructure that is continuously open to new members/users within EUROCHAMP-2. This has led to creation of the first large-scale open data base of experimental data from atmospheric simulation chamber studies.

The Extratropical UTLS, Convection and the TTL

M. Barth presented a brief overview of the workshop entitled "The Extratropical UTLS: Observations, Concepts and Future Directions", which was held in Boulder CO, October 19-22, 2009. The workshop was co-sponsored by the NSF and SPARC and well attended (approx. 90 participants). The program consisted of overview talks, contributed talks and posters organised under the topics of dynamical structure, chemical structure, transport and stratosphere-troposphere exchange, chemistry and microphysics. A SPARC Newsletter article reporting in more detail on the workshop is in preparation. Plans for additional publications include an "IGACtivities" article and a summary white paper.

M. Barth also presented an overview of recent studies of the role of convection and chemistry in the tropical tropopause layer. The 2006 SPARC/IGAC/GEWEX workshop (reported upon in Newsletter No. 28) brought together scientists from the three communities and produced a list of longer term goals, which included establishing a working group composed of members of each of the three communities to develop a framework for collaborative research. Although this working group has not come into being, the workshop has influenced activities within each of the communities. The GEWEX community has implemented suggestions from the 2006 workshop (higher model top, tracers in CRMs). Large-domain, cloud-resolving-scale simulations are beginning but are at early stages – none so far include tracers and/or chemistry. Several of the presentations in the regional workshop attest to Japanese leadership in this field.

For future work there have been suggestions of promoting an idealised case study that would explore the role of cloud microphysics in the TTL water vapour budget, but not with chemistry. An AMMA case study may also meet the needs of large-scale dynamics, cloud physics and chemistry. Another TTL-UTLS workshop may be timely. The AC&C Activity would be an appropriate context for a rejuvenated focus on the role of convection in the TTL.

Discussions on WCRP/SPARC, IGBP/IGAC perspectives and programmatic issues

Discussion periods were scheduled at several points to ensure an effective exchange of thoughts and ideas on a wide range of issues for SPARC as well as those of common interest to SPARC and IGAC and their parent programmes.

S. Seitzinger, Executive Director of IGBP, summarised recent developments in IGBP. The ICSU review of IGBP in 2009 highlighted the need to prioritise and engage in strategic interactions with other partner programmes in GEC research. Initial topics for the IGBP Integration, Synthesis and Exploration theme were identified at the 2009 SC meeting for IGBP, three to receive initial funding from IGBP (Earth-system impacts from changes in the cryosphere, Megacities and coastal zones, GEC and needs of least developed countries). These will contribute to the ICSU Visioning Process which addresses five grand challenges: (1) create the capability to forecast future global environmental conditions and their consequences for people; (2) develop the observation systems needed to manage Global Change; (3) determine how to anticipate, avoid and cope with dangerous Global Change; (4) determine how to achieve collective social action in response to Global Change; (5) develop and evaluate innovative responses to Global Change. An IGBP Open Science Conference will be held in 2012. Its theme will be "Planet Under Pressure: New Knowledge, New Solutions".

For the WCRP, G. Asrar emphasised the need to foster excellence and progress in science, while addressing the demands from sponsors to respond to societal needs and challenges. Funding agencies relate to science if they perceive that new knowledge is being integrated into efforts to address these demands. He noted again the main features of the WCRP Implementation Plan in which the overarching theme of prediction engages the whole range of current WCRP activities. Important emerging issues include determining what is required of future generations of Earth system models and engaging, supporting, and training young scientists.

K. Law summarised key outcomes from the workshop on IGAC Future Directions, held in London in September, 2009. The background for this workshop included the ending of IGBP Phase 2 in 2012/13 and ICSU's reflections about a future structure. The workshop objectives were to examine IGAC science priorities and possible future implementation strategies and structure for coordination of research in atmospheric chemistry. The basic features of the future IGAC structure suggested from deliberations at the London workshop can be summarised as a combination of thematic projects driven by societal needs and coordination of fundamental science addressing big picture questions.

Ideas for thematic projects addressing societal needs could be developed and implemented within AC&C as joint SPARC and IGAC activities. Possibilities for future logistical linkages with SPARC were also discussed at the London workshop. Some possible options include: (a) stay the same as at present with independent IGAC and SPARC projects; (b) stay the same plus create a common coordination structure for fundamental research (*e.g.* related to Atmospheric Chemistry in the Earth System for shorter term foci < 2-3yrs); (c) evolve into a new structure with cross-cutting thematic programmes and common coordination (longer term > 5yrs); (d) merge into one programme on Atmospheric Chemistry in the Earth System (longer term). Although there were mixed opinions on structure options, the London Workshop revealed strong support for closer coordination between SPARC and IGAC and further discussion.

T. Peter summarised the SPARC Legacy document that was prepared as part of the forward-looking process. It emphasises three issues of abiding concern for SPARC: (a) chemistry-climate model validation, (b) assessment of key uncertainties in measurements, and (c) linking various scientific communities.

In the general discussion it was evident that both SPARC and IGAC and their parent organisations (WCRP and IGBP) have recognised the need to embrace new perspectives and objectives. A key principle for success in programmatic developments is that organisational forms and structures must serve the functional requirements that evolve from the combined demands of the science and societal needs. These are continuously evolving and pose ongoing challenges for programme development.

While SPARC and IGAC have much in common, have complementary activities, and benefit by strong ties with each other, they also have distinct foci. The SPARC and IGAC communities may also have different perceptions of how their respective programmes and objectives could benefit (or be harmed) by major changes such as a merger of SPARC and IGAC. Regardless of future programmatic developments, their shared responsibility for the WCRP/IGBP cross-cutting AC&C initiative mandates continued close interaction. In particular, the role of CCMVal should be enhanced in the future to involve a stronger connection to tropospheric chemistry climate models. Although it will continue to focus on climate issues, SPARC may be able to contribute to and complement the strong IGAC focus on air quality through CCMVal.

Whilst it is clear that addressing tropospheric processes in a comprehensive way is beyond its present scope, SPARC must continue to contribute to the understanding of the close dynamical and physical/chemical coupling between the stratosphere and troposphere. These interactions occur on a wide range of spatial and temporal scales, which underlines the importance in this context of devoting more attention to shorter time scale effects, for example the role of the stratosphere in short to medium range prediction and the coupling between stratosphere and troposphere in such prominent tropospheric circulation systems as the monsoons.

SPARC Themes

Detection/Attribution/Prediction

WAVAS-2

C. Schiller summarised progress on the WAVAS-2 Assessment, which is proceeding well. Author and Planning meetings were held in 2009. Chapter meetings will be held in spring and summer of 2010 with a final review meeting to be held near the end of 2010. The expected publication date for the report is mid 2011.

The WAVAS-2 report will have five chapters. In addition to an 'Introduction and Synthesis' chapter, it will include chapters on Data Quality, Supersaturation, and UTS Climatology and Trends. The AquaVIT intercomparison will be discussed among other topics in the Data Quality chapter. A white paper on this campaign is available at **https://aquavit.icg.kfa-juelich.de/AquaVIT/**.

Seasonal and decadal prediction/WGSIP

A. Scaife presented an overview of the activities of the CLIVAR Working Group on Seasonal to Interannual Prediction (WGSIP). There are three main foci for WGSIP activities: numerical experimentation for seasonal-to-interannual variability and predictability; data assimilation, initialisation and seasonal-to-interannual forecasts; advising the CLIVAR SSG on the status of seasonal-to-interannual forecasting.

It is now well recognised that accounting for the influence of the stratosphere remains a largely untapped source of predictability. Key elements of interannual to decadal variability are strongly influenced by stratospheric processes.

The Climate-system Historical Forecast Project (CHFP) would benefit from SPARC participation. The models involved hitherto have been typical of those used for IPCC assessments. A stratospheric extension of the CHFP is now being undertaken by WGSIP. This will involve hindcasts parallel to the WGSIP-CHFP with extended models using the same initial ocean data. Several of the major modelling groups have indicated intentions to participate. SPARC contributions to key diagnostic projects utilised the model output would be very valuable.

Stratosphere-Troposphere Dynamical Coupling

S. Yoden summarised some recent work by Japanese scientists in the general area of stratosphere-troposphere dynamical coupling. The Japanese research project entitled "Assessment of the Stratospheric Effects on Climate Change and Elucidation of their Dynamical Role" includes a group of leading Japanese dynamicists and modellers as coinvestigators. S. Yoden also noted that the XXV IUGG General Assembly (28 June - 7 July 2011, Melbourne, Australia) will include a number of middle atmosphere symposia proposed or co-sponsored by ICMA as well as an ICMA-SPARC joint symposium entitled "Stratospheric Processes and Their Role in Climate Focused on the Southern Hemisphere" and an IAMAS-IAGA joint symposium entitled "External Forcing on the Middle Atmosphere and Lower Ionosphere".

DynVar

P. Kushner has stepped down as coordinator for the DynVar activity. **E. Manzini** has agreed to take over this responsibility. She reported on the status and plans for the DynVar activity. A full-scale model intercomparison was initially planned. However, given the emphasis by many of the modelling groups on CCMVal activities in the last few years, additional coordinated runs were not feasible, and a DynVar workshop was not held in the past year. A substantial amount of the applied and theoretical research that was proposed for DynVar has actually been done by different groups in the past two years. While the long-term goals of DynVar are unchanged, E. Manzini has undertaken a restructuring of the DynVar activity to facilitate future efforts. The running of the activity is conducted by the coordinator in consultation with the DynVar Committee (Marco Giorgetta, Judith Perlwitz, Lorenzo Polvani, Fabrizio Sassi, and Adam Scaife), who provide a broad array of expertise.

A new aspect of DynVar is to establish a SPARC-CLIVAR connection focused on the role of the stratosphere on weather and climate predictability. In the coming years, an optimal way for DynVar to pursue its goals is to exploit the data sets that will be produced for assessment purposes, such as the high-top CMIP5 runs, and the stratospheric seasonal prediction hindcasts produced as part of WGSIP's Stratosphere Historical Forecast Project (SHFP) with high-top models. A DynVar workshop is being planned for late 2010, likely in Boulder, CO, USA. Further details and information on the DynVar activity and forthcoming workshops will continue to be posted on the SPARC DynVar website, **www.sparcdynvar.org**.

Chemistry-Climate Coupling

WMO/UNEP Ozone Assessment Update

G. Bodeker presented an update on the status of the 2010 WMO/UNEP Scientific Assessment of Ozone Depletion. There will be a number of key SPARC contributions to the report. It will be the first assessment to consider the effects of stratospheric change on climate. The availability of the CCMVal report on Evaluation of Chemistry-Climate Models removes the requirement to include model evaluations as part of the assessment. The availability of the Report on Halogen Chemistry resolves the recent disconcertment about the ClOOCl UV absorption cross-section measurements. The availability of CCMVal sensitivity simulations would allow a more refined analysis of the effects of climate change on ozone recovery. The target date for the availability of the final version of the assessment report in preprint form is December 30, 2010 with a final distribution of printed copies by March 2011.

The SPARC special report on CCM validation will be valuable to the 2010 ozone assessment. It is now timely to include its role in the 2014 ozone assessment in the planning for CCMVal-3 in concert with other AC&C activities.

Cross-Cutting Issues

The Polar Initiative

The role of the polar regions in climate was raised by SPARC at the 2008 meeting of the WCRP JSC as an important cross-cutting issue for the WCRP in the near future. The JSC endorsed an effort aimed at using IPY results and other available knowledge and capacity to undertake an assessment of polar predictability at various time scales. V. Ryabinin reviewed progress and current efforts to move this initiative forward. Follow-on discussion between SPARC, JPS, and other WCRP projects have suggested an overall focus on the interaction of polar regions with lower latitudes, processes that affect the poles, and interactions between various components of the climate system in the polar regions. The initiative will take advantage of opportunities such as the revolution in ocean *in situ* observations and their assimilation, IPY data, and the possibility of an International Polar Decade (IPD).

A scoping workshop is planned to exchange thoughts and information between various WCRP communities on polar prediction. T. Shepherd has agreed to serve as chair of the Scientific Organizing Committee (SOC). The target date for the workshop is late 2010. A Polar Initiative web site will be established and maintained by the SPARC Office.

Geoengineering

Because of the inadequacy of global CO_2 emission reductions, the potential need to look to geoengineering to mitigate the surface warming due to increasing atmospheric CO_2 has become a topic of serious discussion in the broader scientific community. This has motivated the forthcoming comprehensive Royal Society report on geoengineering. T. Peter gave an overview of this discussion, and of recent modelling results relevant to the effect of the Crutzen proposal to introduce and maintain an artificial stratospheric aerosol layer as a means of offsetting the surface warming associated with increasing CO_2. The aerosol size distribution is important in determining any such effect. The validity of the particle size assumptions in the Crutzen proposal and some other initial modelling studies have been questioned in more recent studies that account for microphysical processes in the evolution of the aerosol size distribution. Formation of larger particles than after volcanic eruptions may accompany continuous SO_2 emissions in the stratosphere. Potential repercussions include a warmer tropopause, moister stratosphere, changed dynamics, and more ozone loss.

The question of what role SPARC should play in the debate on geoengineering (specifically in response to the Crutzen proposal) was first raised, but not resolved, at the 2007 SSG meeting in Bremen. As government interest in geoengineering is growing rapidly, it is vital for organisations such as SPARC to facilitate research that clarifies the benefits, dangers, unintended consequences, feasibility, and other scientific aspects of the issues, so that policy-makers can make well-informed decisions.

Gravity-wave Initiative

J. Alexander reviewed progress and current objectives of the gravity-wave activity. A major outcome of the 2008 workshop (see the report in SPARC Newsletter No. 31) has been the preparation of a review paper: "A Review of Recent Developments on Gravity Wave Effects in Climate Models and the Global Distribution of Gravity Wave Momentum Flux", which has been submitted to the Quarterly Journal of the Royal Meteorological Society.

A number of key issues remain to be explored further and understood better. This has motivated additional new activities for the coming two years. The Gravity Wave Project - An International Team for Merging Space-Based Observational Constraints for Gravity Wave Parameterizations in Climate Models has been funded by the International Space Science Institute (ISSI). The goal of the project is to create a self-consistent data set of atmospheric gravity wave momentum fluxes and propagation properties suitable for climate and weather forecasting applications. The SPARC SSG has endorsed this project. Complementary to this new activity a Chapman Conference proposal has been submitted to the American Geophysical Union for a conference entitled "Atmospheric Gravity Waves and their Effects on the General Circulation and Climate". There have been recent advances on this topic and the community is growing. The meeting would provide a chance for this community to come together to assess the recent results and forge the interdisciplinary collaborations that are needed to address the current issues. The SPARC SSG endorsed co-sponsorship of this conference.

Solaris

K. Kodera presented an update on the SOLARIS activity. The modelling initiatives within this activity have been to a considerable extent superseded by the CCMVal requirements in the past year. There are a number of outstanding issues concerning observing and modelling the atmospheric response to variability of solar forcing. Inhomogeneity in long-term observational data and the stability of analyses using short-term data are factors in evaluating solar variability signals. Some analysis methods (*e.g.* multiple regression) may also be problematic because forcings may be correlated (*e.g.* both SSTs and the QBO have decadal-scale variations) and responses are nonlinear and dependent on the basic state. Model biases (*e.g.* the tendency for planetary waves to propagate too easily toward the equator in some CCMVal-2 simulations) are also a factor in simulating the response to solar variability. The importance of resolving the spectrum of solar variability in modelling experiments needs to be assessed. The next SOLARIS workshop will be held in March, 2010 at the GFZ German Research Centre for Geosciences in Potsdam, Germany.

In a brief presentation, **M. Geller** drew attention to recent discussions between SCOSTEP, IAGA, and other parts of IUGG to assess how well the IPCC has looked into the role of solar forcing in global climate change.

Data Assimilation Working Group (SPARC-DAWG)

S. Polavarapu summarised aspects of presentations in the SPARC-DAWG meeting that was held in conjunction with MOCA-09, as well as from selected data assimilation papers in the MOCA-09 conference. Invited talks in the SPARC-DAWG meeting dealt with using data assimilation (DA) to identify sources of error in tropospheric climate predictions, using DA to identify missing or incorrectly represented forces in climate models, and the role of DA in prediction. Although holding the SPARC-DAWG meeting in conjunction with the MOCA-09 meeting offered the opportunity to bring the work of the SPARC-DAWG to the attention of a wider audience, competition from parallel sessions was a significant distraction. The 2010 SPARC-DAWG dedicated workshop will be hosted by the Met Office in Exeter, UK.

Proposal for a SPARC Data Initiative

S. Tegtmeier and **M. Hegglin** presented a proposal for an initiative to address a number of outstanding issues highlighted by the CCMVal activity in regard to the availability and use of chemical observational data sets. While a variety of such data sets are available, it is not necessarily known which data set is most reliable for a particular application. Conflicting results may be obtained when comparing models to different data sets. In the context of CCMVal, scores for a specific diagnostic are dependent on the data set used, making comparisons less meaningful and increasing uncertainties in assessments. Similar difficulties were manifest in regard to comparing and evaluating middle atmosphere model climatologies in the context of the GRIPS project and led to the production of the SPARC Intercomparison of Middle Atmosphere Climatologies (SPARC Report No. 3). There is a need for a similar assessment of the available data sets for chemical trace gases. The proposed report and associated climatologies will offer guidance for the use of chemical trace gas observations from space based instruments. It will involve the following steps: (a) establishing a data portal for chemical observations in collaboration with the space agencies and assessing the state of data availability; (b) compiling climatologies of chemical trace gases (*e.g.* zonal means, variability, seasonal evolution, annual means) in collaboration with the instrument PIs; (c) creating a detailed inter-comparison of these climatologies, summarising useful information and highlighting differences between the data sets.

The proposal was endorsed by the SSG. The initial action will be to hold a workshop in early 2010 to assemble the author team, define the report structure, and address issues involved in coordination of the data initiative. The target completion date for the report is May 2012.

Connections with WCRP Projects and Panels

CLIVAR

H. Cattle (director of the CLIVAR IPO) gave an overview of the CLIVAR Project and highlighted activities which have common interests and links to SPARC. The overall mission of CLIVAR is to observe, simulate and predict changes in the Earth's climate system with a focus on ocean-atmosphere interactions, enabling better understanding of climate variability, predictability and change, to the benefit of society and the environment in which we live. CLIVAR has a number of working groups and panels, some of which address issues that are related to SPARC activities and themes, for example the JSC/CLIVAR WG on Coupled Modelling (WGCM) and the WG on Seasonal to Interannual Prediction (WSGSIP), both of which have been noted above.

There are a number of CLIVAR-SPARC

links that are well established and others that are being established (*e.g.* through WGSIP as discussed by A. Scaife). There are also potential SPARC links to CLIVAR/ GEWEX monsoon studies. A SPARC/ CLIVAR Workshop on 'The role of the stratosphere in seasonal, decadal and longer-term climate predictability' may be worthwhile in the near future. There are also potential SPARC links to CLIVAR/ GEWEX monsoon studies.

WOAP

The last WOAP meeting (WOAP-3) was held in Boulder in September, 2008 and reported upon at the 2008 SPARC SSG meeting. WOAP-4 will be held in March, 2010. Key issues of concern to SPARC that may be addressed include (a) possible WOAP actions to address gaps in satellite ozone and trace gas profile measurements, (b) Essential Climate Variables, (c) SPARC input and requirements for reanalysis, (d) reprocessing of stratospheric data sets/ SPARC data initiative, and (e) SPARC data management issues that may need to be addressed by the WOAP Task Group on Data Management (TGDM).

Coordination with Other Agencies and Programmes

Space Agencies

JAXA Earth Observation Satellite Programs associated with SPARC

T. Igarashi presented an overview of the long-term plan of JAXA Earth Observation, SPARC related observations, sensors, space platforms and data products. JAXA has been developing, operating, and providing data for the atmospheric research and climate change science communities and user organisations. GOSAT L1 products will be released on 30 October 2009, and L2 and upper level products will be released at the end of January 2010. SMILES first data obtained on 12 October 2009 were released on 19 October 2009. For the future programmes, considering scientific significance and societal needs, JAXA is conducting R&D of geostationary atmospheric and meteorological observation sensors for the monitoring of air pollution, air quality and weather (vertical profile of temperature, water vapour), sounders and lidars expected for 3D profiling as well as radars. Climate change challenges JAXA to tackle the integration of multi-satellite data, weather and climate models. There are many possibilities of international collaboration such as NPOESS/GCOM, OCO/GOSAT, GPM, EarthCARE, *etc*.

Canadian Missions, Activities, and Mission Concepts relevant to SPARC and IGAC

T. Piekutowski presented an overview of Canadian Space Agency activities, currently operational and planned instruments and missions. The Canadian atmospheric science community has a long-standing interest and expertise in atmospheric composition and dynamics. The CSA invests in space-borne atmospheric remote sensing, in production and validation of high quality data, and in interactive chemistry-climate modelling. The CSA is likely to continue investing in atmospheric science missions that help to understand ozone recovery, air quality and the processes linking these with climate. The CSA places great value in partnerships with Canadian scientists, government departments and industries, international organisations and with other space agencies. The CSA supports the science operations of ACE-FTS, MAESTRO, OSIRIS and MOPITT through contracts to the Universities of Waterloo, Toronto and Saskatchewan. The CSA also supports a range of validation, modelling, and international research activities including intensive ACE validation campaigns at the Polar Environmental Research Laboratory (PEARL), the Canadian Middle Atmosphere Model and its Data Assimilation System (CMAM-DAS) through the C-SPARC Network, and the SPARC International Project Office.

NASA Space-Based Research Activities, NDACC activities

M. Kurylo gave an update on current and planned NASA activities and missions of relevance to SPARC. NASA's Earth Science Division recently completed its biennial senior review to determine those missions that will continue to be funded for operation beyond their primary design life. Nearly all of NASA's Earth Science satellites fell under this review, including Aura, CALIPSO, and Aqua (*i.e.*, missions with some sensitivity in the UTLS). All of these missions were extended for 2 years with a provisional additional 2 years (pending the next senior review). M. Kurylo also summarised the status of several existing and planned atmospheric chemistry missions and summarised developments and some features for the proposed NASA-CSA Chemical and Aerosol Sounding Satellite (CASS). M. Kurylo also gave an overview of NDACC activities pertinent to SPARC. Examples include observation campaigns, the Working Group on Water Vapor, and NDACC/GAW/IGACO Ozone Theme Meetings.

ESA PREMIER Mission

M. Hegglin presented an overview of the ESA PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation (PREMIER). PREMIER is a candidate mission for implementation by ESA competing for selection in early 2011 (after a user consultation meeting in late 2010). The mission objectives are (a) to investigate processes controlling global atmospheric composition in the UTLS by resolving 3-D structures of trace gases, thin cirrus and temperature in this region on finer scales than has previously been possible from space, and (b) to study links with surface emissions and pollution by exploiting synergies with nadir-sounders on EPS-Metop. For the first time, 3D-distributions of various atmospheric variables will be observed from space in the height range most important to climate. The high-resolution observations will allow a better quantification and characterisation of the complex dynamical and chemical processes in the UTLS. The development schedule is compatible with launch during 2016 as Earth Explorer 7 (PREMIER assessment report).

WMO-GAW

L. Jalkanen gave an overview of the WMO Global Atmosphere Watch Programme (GAW). GAW is the atmospheric chemistry component of the Global Climate Observing System (GCOS). GAW focuses on global long-term networks for greenhouse gases, ozone, UV, aerosols, selected reactive gases, and precipitation chemistry. GAW is a partnership involving contributors from 80 countries and collaboration with other networks, projects and initiatives. GAW is coordinated by the Atmospheric Environment Research Division (AER) of WMO Research Department. Currently, GAW coordinates activities and data from 26 Global, 410 fully operational Regional, and 81 fully operational Contributing stations. The GAW Strategic Plan (GSP) for years 2008-2015 has overarching themes of long term systematic monitoring of atmospheric chemical and physical parameters globally, analysis and assessment, and development of a predictive capability. GAW publications include annual WMO Greenhouse Gas Bulletins and WMO Arctic and Antarctic Ozone Bulletins. These are available through its web site (**http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html**), which also provides a comprehensive summary of its programme and products.

SPARC Programmatic Issues

WCRP Science Conference/SPARC General Assembly

After considerable discussion the SSG decided to defer the next GA to 2014. See the short article by the SPARC co-chairs below explaining this decision.

The SPARC Data Center

P. Love, the new SPARC Data Center Scientist, gave a brief update on the status of the Data Center. Support for the SPARC Data Center is provided by NASA and is currently committed through August, 2010. System and memory upgrades in the last 2 years substantially increased the system capacity, which now substantially exceeds the current usage. An online plotting facility is under development.

Update on SPARC Office Activities and Funding Status

During the past year the SPARC-IPY activity has wrapped up. The SPARC Office operational activities in the last year have included publication of newsletters (#32 and #33), providing local organisational assistance for the WAVAS-2 and CCMVal workshops, and coordinating travel funding for SPARC workshops (WAVAS-2, CCMVal, Volcano, ExT UTLS, Limb) and for the SPARC SSG meeting. In addition, the normal operational activities include ongoing interaction and cooperation with the WCRP JPS and other WCRP projects and working groups on a range of issues and actions.

The mandate of the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) has recently been extended for one year but there is no indication that there will be a further extension and its operation is expected to wrap up in early 2012. The largest portion of the cash support for the SPARC IPO is provided by CFCAS. An application to CFCAS for extension of support for the SPARC IPO through December 31, 2011 has been approved. There are no prospective Canadian funding sources to replace the CFCAS support beyond the end of its mandate. In the absence of this support it will not be possible to maintain the SPARC IPO in its current location after 2011. Alternative locations and sources of support are being considered.

The 18th Session of the SPARC Scientific Steering Group

The 18th meeting of the SPARC SSG will be held in the period January 5-8, 2011 at the Indian Institute of Tropical Meteorology (IITM) in Pune, India at the invitation of SSG member Panuganti C. S. Devara. Following the examples of the Bremen and Kyoto meetings, a 1-2 day local workshop at IITM preceding the SSG meeting is planned.

Closure of the 17th Session of the SSG

The SPARC SSG meeting closed at noon, October 31. All present joined the Co-Chairs in thanking Masato Shiotani and many of his Japanese colleagues including former SPARC SSG members Sachiko Hayashida and Shigeo Yoden for hosting the meeting, arranging the excellent facilities and local support for the SSG meeting and for organising the very successful regional workshop that preceded it.

The Next SPARC General Assembly

Dear SPARC community — Many of you have told us that you find it very unfortunate that the quadrennial SPARC General Assemblies (GAs) are held in the same year as the Quadrennial Ozone Symposia (QOS), as it means two major international conferences with a stratospheric focus in the same year. We have considered this situation and decided that the optimal arrangement would be to have the SPARC GAs two years out of phase with the QOS. (Moving the GAs one year forward or backward would bring them into conflict with the IAMAS/IUGG Assemblies, which also have strong stratospheric components.) This configuration would also allow for the possibility of holding the SPARC GAs jointly with IGAC Science Conferences (SC), which are held every two years.

Accordingly, we will be delaying our next SPARC GA until 2014. The intervening period will provide an opportunity for the SPARC community to interact more strongly with its many partners. In 2011, the WCRP will hold an Open Science Conference (date and venue are still TBD). This will be a great opportunity for us to present SPARC science and build new scientific connections with the rest of the WCRP, as SPARC transitions into a project with a stronger link to the troposphere. In 2012, there will be an IGAC SC and a QOS, both of which will feature strong SPARC components.

The WCRP Open Conference in particular will be a unique opportunity, and should be seen as an 'interim GA' half way between our regular GAs. The WCRP is our mother organisation, and the last such meeting was held 10 years ago. It's fair to say that at that time SPARC was quite separate from the rest of the WCRP, but that is no longer the case as there are new connections emerging all the time. The WCRP Open Conference is thus a tremendous opportunity for students and post-docs in particular to see the broader context of their work. We strongly encourage the SPARC community to get involved in all of these meetings, as well as the IUGG and IAMAS Assemblies in 2011 and 2013, and look forward to our next GA in 2014.

Tom Peter and Ted Shepherd, SPARC co-Chairs

WCC-3, not just "another climate conference"

V. Ryabinin, World Climate Research Programme, Geneva, Switzerland (VRyabinin@wmo.int)

On 31 August - 4 September 2009, the third World Climate Conference (WCC-3) was held in Geneva, Switzerland. It was organised by the World Meteorological Organisation (WMO) with 23 partners, including the World Climate Research Programme (WCRP), and received support from 16 countries and the European Commission. The two previous WCCs were also organised by the WMO and held in Geneva in 1979 and 1990. The first WCC resulted in the foundation of the World Climate Programme and WCRP as one of its components, and led to the establishment by WMO and UNEP of the IPCC (Intergovernmental Panel on Climate Change). The second WCC resulted in the establishment of the Global Climate Observing System (GCOS), and stimulated the birth and subsequent endorsement of the United Nations Framework Convention for Climate Change (UNFCCC). It is possible to state, therefore, that the WCCs have shaped the process of developing all aspects of humankind relations to climate, from observations and research, through assessments and application of knowledge, to corresponding policy development.

The WCC-3 consisted of two segments: the expert and the high-level. 200 Speakers and 1500 participants in the expert segment of the conference reviewed advances in climate science, observations, information, assessments, *etc*. Many sessions of this segment were organised to, firstly, outline needs in climate products and, secondly, evaluate the feasibility of future climate service to deliver on these needs. After the conclusion of the expert segment, a statement was agreed upon between conveners and responsible persons that gave a unifying perspective on the subject from a wide cross-section of climate scientists, expert providers of climate information and the users of climate information and services. The Statement called for major strengthening of the essential elements of climate services including:

- The Global Climate Observing System and all its components and associated activities; and provision of free and unrestricted exchange and access to climate data;
- The WCRP, underpinned by adequate computing resources and increased interaction with other relevant global climate research initiatives;
- Climate services information systems; taking advantage of enhanced existing national and international climate service arrangements in the delivery of products, including sector-oriented information to support adaptation activities;
- Climate user interface mechanisms focused on building linkages and integrating information, at all levels, between the providers and users of climate services;
- Efficient and enduring capacity building through education, training, and strengthened outreach and communication.

The high-level segment, which benefitted from the presence of numerous Heads of State, Prime Ministers, Heads of UN Agencies and Programmes, including the UN Secretary-General, agreed on a declaration in which it was decided to establish a Global Framework for Climate Services (GFCS).

The main goals of the GFCS, as they are seen now, will be to "enable better management of the risks of climate variability and change and adaptation to climate change at all levels, through development and incorporation of science-based climate information and prediction into planning, policy and practice". The GFCS is proposed as a long-term cooperative arrangement through which the international community and relevant stakeholders will work together to achieve its stated goal. The following GFCS components are envisaged:

- Observation and Monitoring,
- Research, Modelling and Prediction,
- Climate Services Information System, and
- User Interface Programme.

Taking into account the outcomes of WCC-3, the Framework will be further developed under the guidance of an *ad hoc* task force consisting of high-level independent advisors, with inputs from a broad-based network of experts and in consultation with governments, partnering organisations and relevant stakeholders. The outcomes of the fifteenth session of the Conference of the Parties to the UNFCCC (COP 15), as well as the special requirements and vulnerabilities of developing countries, especially the least developed countries and small-island states, will also be taken into consideration.

Based on agreements at the WCC-3, the WMO is taking the lead in putting together a task force of high-level independent advisors. The WMO Congress in 2011 will review the recommendations with a view to adopt the proposed plans.

WCC-3 preparations required significant effort from the WMO Secretariat and Partners. According to the impressions of the attendees, WCC-3 was a great success. WCRP-affiliated scientists took an active part in preparing the Conference. Prof. Martin Visbeck, a Co-Chair of CLIVAR, was the Chair of Programme Committee. Two of the most well-attended sessions of WCC-3 were on seasonal and decadal climate predictions, in preparation of which WCRP-affiliated scientists took the lead. Many of our colleagues attended the conference as speakers, discussants, and conveners. The WCRP organised a booth where participants could learn more about WCRP and its activities. The main task for the WCRP stemming from the WCC-3 will be to analyse the science requirements for the GFCS and to organise our community to deliver on them.

White papers prepared for the Conference and talks given there are accessible through the WMO website, **http://www.wmo.int**.

SPARC Volcano Workshop
8-9 July 2009, Zurich, Switzerland

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Introduction

Major volcanic eruptions in the tropics can influence the global climate on the scale of months to years (see **Figure 1**). An extreme example is the eruption of Mt. Tambora, which led to a year without summer in 1816 (*e.g.* Oppenheimer, 2003). The most recent large tropical volcanic eruption was the Mt. Pinatubo eruption in June 1991 in the Philippines (15°N), which has been relatively well characterised by observations. However, even in this case there are many uncertainties due to instrument quality and data gaps. This complicates the comparison of modelling results with observations. Aerosol and climate models struggle to quantitatively represent the atmospheric effects of the Mt. Pinatubo eruption. On the initiative of Patricia Heckendorn and Tom Peter, the SPARC volcano workshop was organised with the aim of identifying and constraining uncertainties in observations and modelling studies of large volcanic eruptions.

Since the publication of the ASAP (Assessment of Stratospheric Aerosol Properties) report by SPARC (Thomason and Peter, 2006) some improvements in observational analysis and in aerosol and climate modelling have been achieved. The main focus of the ASAP report was on understanding remote and *in situ* observations in terms of microphysical processes, whereas less emphasis was given to the radiative impact of volcanic eruptions, a perspective now added by the volcano workshop.

The 2-day workshop was structured in 4 thematic blocks:
(I) Observations of the eruption of Mt. Pinatubo.
(II) Modelling of stratospheric aerosols formed after volcanic eruptions.
(III) Modelling of historic/paleo volcanic eruptions.
(IV) Radiative, chemical and dynamical response to volcanic eruptions.

Part I: Observation of Mt. Pinatubo eruption in 1991

Despite the fact that the Mt. Pinatubo eruption in June 1991 was the most well-observed large volcanic eruption, the peak of the stratospheric aerosol cloud was not well characterised. A major obstacle was that for satellite instruments measuring by occultation, the lower stratosphere became opaque during the first few months after the eruption. Also, while the ground-based lidar network is well established in the Northern Hemisphere, it is much less dense in the tropics, where the volcano was located, and in the Southern Hemisphere, where a large part of the sulphate was transported. The correct sulphur emission mass and location are important input parameters for aerosol (and climate) models.

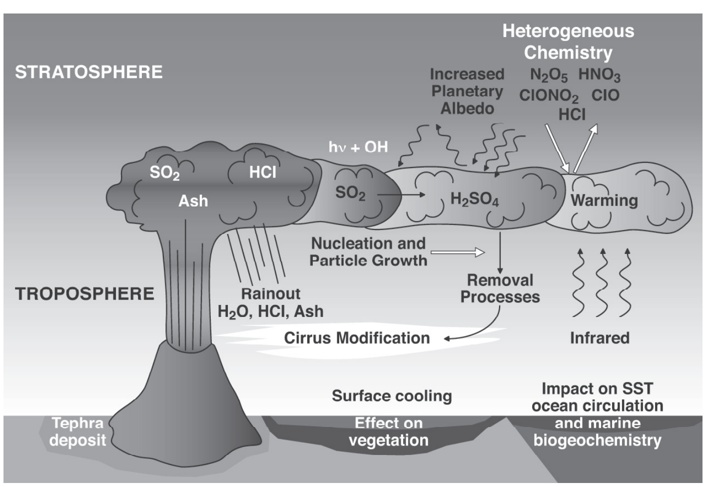

Figure 1. Schematic picture of large volcanic eruption and its impact on climate. (From U. Niemeier, modified version after McCormick et al., 1995).

SAGE II satellite measurements provide valuable input for building a consistent long-term stratospheric aerosol data set, due to their wide time and space coverage. During the first year after the Mt. Pinatubo eruption, the tropical atmosphere below 23 km became opaque for SAGE II, due to saturation effects. This is the region of largest stratospheric aerosol loading. **L. Thomason** discussed how to construct a gap-free aerosol data set to serve as input for climate models. A first attempt in this direction was published by Russell *et al.* (1996), who applied a previous version of the SAGE II data and assumed constant values in the data gaps equal to the nearest measured value. The ASAP report (Thomason and Peter, 2006) improved the gap-filling by using lidar data from Camagüey, Mauna Loa and San Carlos. This led to increased extinction values in the data gap regions. But as the main aerosol cloud was only occasionally seen above these stations, this estimation of the extinction in the tropics could still be wrong by up to a factor of 2. Outside the gap-filled region the uncertainties are in the range of 10-20 %.

The OPC (Optical Particle Counter) enables *in situ* measurements of the particle size distribution, from which quantities of geophysical interest can be derived, such as aerosol surface area and volume densities, and extinctions at various wavelengths (*e.g.* Deshler *et al.*, 2003). The instrument also allows for tracking the evolution of aerosol size distribution. **T. Deshler** presented OPC measurements from Laramie Wyoming (US), which date back to 1971. Additional OPC measurements are available from campaigns in Mildura (AU), Lauder (NZ), McMurdo (ANT) and Kiruna (SE). The accuracy of the instrument is determined by pulse width broadening and Poisson counting statistics leading to errors of ~30-40 % on any distribution moment. Deshler *et al.*

(2003) provide spectral size distribution retrieved from OPC measurements assuming 1-2 lognormal distributions. Typical uncertainties for the distribution width are about 20 %, for the mode radius 30 % and for the surface area density (SAD) 40%.

M. Kovilakam showed a comparison of the SAD retrieved from OPC measurements at Laramie, Wyoming and SAGE II measurements. During volcanically perturbed times the data agree within 50%. Agreement is worse during background conditions: at these times OPC surface area densities are found to be larger than SAGE II by about a factor of two (see **Figure 2**). The reason for this could be that SAGE II does not see particles smaller than 50 nm.

Chemistry-climate models need spectrally resolved optical properties and SAD of the stratospheric aerosols as boundary conditions. These quantities are defined by the size distribution of the aerosols, the H_2SO_4 weight percentage and the refractive index. A common method to define the aerosol size distribution is by fitting of the extinction data to a mono-modal lognormal distribution and making assumptions on the distribution width. However, with a mono-modal lognormal distribution it is not possible to obtain sufficient accuracy for both SAD and optical properties (especially extinction in the IR) simultaneously. **B. Luo** presented results from an improved retrieval of aerosol size distribution from satellite extinction measurements using several extinction measurements and assuming a bimodal lognormal distribution.

Part II: Modelling of stratospheric aerosols formed after volcanic eruptions

Since Mt. Pinatubo is the best characterised large volcanic eruption, it makes sense to validate microphysical aerosol models by simulating the Mt. Pinatubo eruption. Aerosol models help to understand the importance of different micro-physical processes involved in the aerosol formation. For example, testing of geoengineering ideas as proposed by *e.g.* Budyko (1977), Turco (1980) and Crutzen (2006) requires reliable models for predicting the effect on climate and on atmospheric chemistry.

H. Graf showed results of the plume model ATHAM (Active Tracer High resolution Atmospheric Model) (*e.g.* Textor *et al.*, 2006, Herzog *et al.*, 2003). The precise meteorological conditions are important to determine the neutral buoyancy height. The increased entrainment of ambient air dilutes the bulk concentration and increases buoyancy. Changes in tropospheric humidity could lead to a shift in the neutral buoyancy height of ash by roughly 5 km. The maximum overshoot height is defined by the exit temperature. One outcome of the discussion was that one-dimensional models are suitable for retrieving the maximum height, whereas calculation of the neutral buoyancy height requires 3D models.

In the ASAP report, the 2D AER (Atmospheric and Environmental Research Incorporation, Lexington, MA, US) aerosol model showed an overall convincing performance (Thomason and Peter, 2006). Using this model **D. Weisenstein** showed sensitivity tests for the Mt. Pinatubo eruption with improved transport characterisation and boundary conditions. She showed that these changes allow for better capture of the first few months after the eruption, but later the residence time of the aerosols is too short. The aerosol size distribution is strongly dependent on the spatial distribution of the initial SO_2 cloud. In **Figure 3** annual mean SAD for 1992 from the AER aerosol model are compared with SAD retrieved from SAGE II measurements.

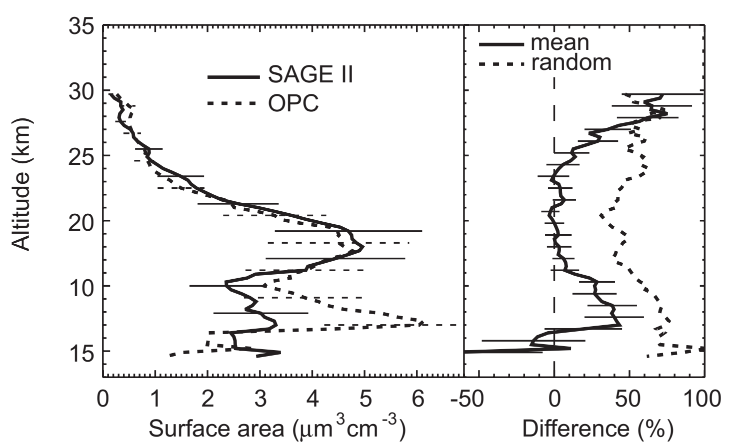

Figure 2. Comparison of surface area density derived from 30 coincident OPC and SAGE II profiles over Laramie between 1984 and 1999 (Figure 4.49 in Thomason and Peter, 2006).

U. Niemeier showed Mt. Pinatubo simulations with the improved MA-ECHAM5/HAM model. Generally, the model compares well with observations (Niemeier *et al.*, 2009). The model was mainly improved by the reduction of the distribution width of the coarse mode of the aerosol size distribution (compare M7 setup 2 (old version) with M7 setup 3 (new version) in **Figure 4**). The lifetime of sulphate depends strongly on the location of the volcano, and is longest in case of a tropical eruption, as well as on particle size and available OH. In the first weeks after a very large eruption, the transport of the volcanic cloud is determined by radiative heating processes causing strong turbulence and a rotation of the cloud in non-tropical areas.

The coupled aerosol climate model MAECHAM5-SAM2 is a suitable model for studies of stratospheric background

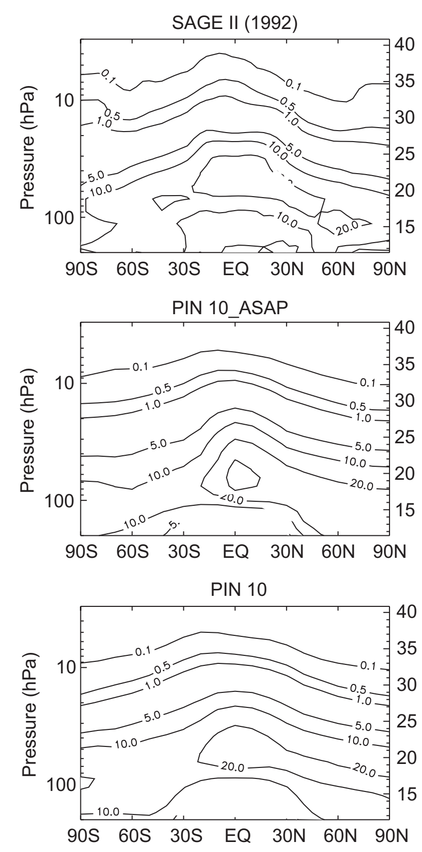

Figure 3. Annual mean, zonal mean SAD in 1992 retrieved from a) SAGE II, b) AER aerosol model with 10 Mt S input (both adapted from Thomason and Peter, 2006), c) improved AER aerosol model with 10 Mt S input (Heckendorn et al., 2009.)

aerosol, as presented by **R. Hommel** (Hommel, 2008). SAM2 is based on a sectional scheme with 35 aerosol size bins. The representation of atmospheric dynamics, such as the quasi-biennal oscillation (QBO), strongly influences the modelled distribution of aerosol mixing ratio in the stratosphere, and affects the aerosol size distribution through the modulation of formation and growth processes of ultra-fine particles (Hommel *et al*., 2010). The latter has an impact on model estimates of particle size integrated parameters like the aerosol surface area density, which is seen to be modulated by up to 30% relative to conventional aerosol coupled GCM's.

Insights from a box model inter-comparison study under Pinatubo conditions (Kokkola *et al*., 2009) revealed that modal and sectional aerosol schemes are in principle able to capture the evolution of Mt. Pinatubo aerosols. However, all modules have to be adapted individually to be applicable for global climate applications, and remaining discrepancies can be seen in **Figure 4**.

Part III: Modelling historic/paleo volcanic eruptions

Quantifying uncertainties in proxy and modelling data on historic volcanic eruptions without direct extinction measurements is a challenging task. There are high uncertainties in emission strength, timing and location, but also in the dynamical state of the ocean and atmosphere (*e.g*. ENSO).

C. Timmreck presented recent research activities at MPI Hamburg and its collaborating universities such as the "Super Volcano Project"[1] and the Millenium Project. Based on these research lines, she highlighted the importance of ensemble runs due to considerable model variability. Interaction of large volcanic eruptions with tropical Pacific dynamics (ENSO) is important factor, and will be the subject of further investigation. The MPI Earth System Model simulated a volcanic eruption from 1258 AD, and the results showed that only aerosol particle sizes substantially larger than observed after the Mt. Pinatubo eruption actually yield temperature changes consistent with terrestrial Northern Hemisphere summer temperature reconstructions. These results challenge the often-made assumption that stratospheric sulphur emissions from volcanic eruptions, and the immediate or longer-term temperature response correlate in a simple manner (Timmreck *et al*., 2009).

[1]http://www.mpimet.mpg.de/en/wissenschaft/working-groups/super-volcanoes.html

Another interesting historic volcanic eruption is the one of Tambora in 1815, which led to the "year without summer" in 1816. **F. Arfeuille** noted that large injections of halogens by this eruption could have had a significant impact on stratospheric ozone. Preliminary results of the Tambora simulation with the AER aerosol model show that the mode radius is larger than for the Mt. Pinatubo eruption. The larger particles lead to a shorter stratospheric aerosol lifetime due to enhanced sedimentation loss. Therefore, 1.5 years after the eruptions of Tambora and Mt. Pinatubo, the extinctions are comparable in magnitude.

S. Brönnimann showed composites of the lower stratosphere for the boreal winters following the eruptions of Krakatoa, Santa Maria, Mt. Agung, El Chichon and Mt. Pinatubo. The composites were based on the one hand on observations (*i.e*. reanalysis data supplemented back in time with statistically reconstructed upper-level fields from Griesser *et al*., 2009) and on the other hand on an ensemble of CCM simulations (SOCOL model, Fischer *et al*., 2008). The observations show surprisingly small variability with ubiquitous strengthening of the polar vortex in the first winter after the eruptions, unlike the model, which shows only a slight strengthening in the ensemble mean with large variability. A possible explanation could be the interference with the modelled El Niño in almost all cases, which would tend to weaken the vortex, while in reality the volcano effect might dominate over El Niño. The model ensemble seems to exhibit both El Niño and volcanic influences.

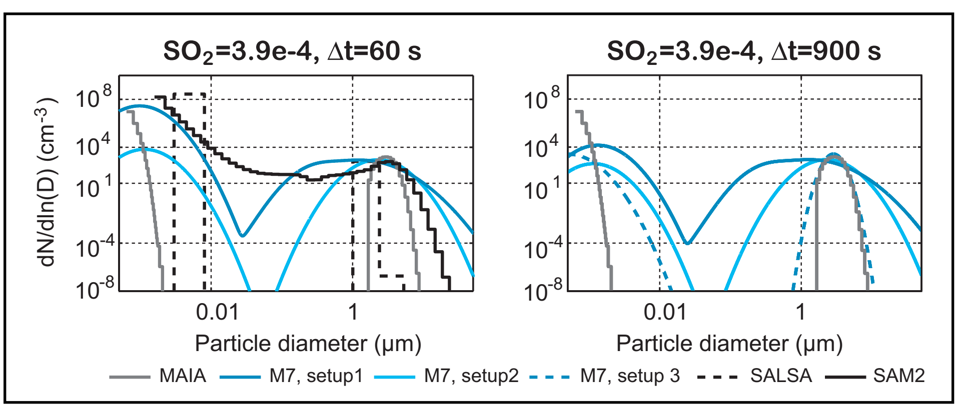

Figure 4. Aerosol number size distribution at noon on day 10 (time step equal to 900 s) for the reference model (MAIA) and MA-ECHAM5/HAM (M7) in one box with initial SO_2 concentration of 3.9×10-4 kg/kg (adapted from Kokkola et al., 2009)

Part IV: Radiative, chemical and dynamical response to volcanic eruptions

Many GCMs (general circulation models) and CCMs have problems in correctly modelling the climatic impact of volcanic eruptions. For instance, CCMs often overestimate the lower stratospheric warming (Eyring *et al*., 2006). Furthermore, GCMs have problems in correctly modelling the tropospheric dynamical feedback after large volcanic eruptions (Stenchikov *et al*., 2006).

Volcanic eruptions do not only produce a net surface cooling during the years following the eruption, but also produce long-term impacts on the ocean's subsurface temperature and steric height (changes of the sea level due to temperature and salinity changes) that accumulate at the current frequency of explosive volcanic events. **G. Stenchikov** showed with CM2.1, the recent GFDL coupled climate model (Delworth *et al*., 2006), that the accumulated averaged volcanic ocean heat content anomaly reaches about 1023 J, and offsets about 1/3 of the anthropogenic warming. After the Tambora and Mt. Pinatubo eruptions, the heat content below 300 m was reduced for decades (see **Figure 5**). Deep ocean temperature, sea level, salinity, and MOC (meridional overturning circulation) have a relaxation time of several decades to a century. This suggests that the Tambora subsurface temperature and sea level perturbations could have lasted well into the 20th century.

S. Fueglistaler showed that ERA-interim does not show a significant temperature change at the tropical tropopause after

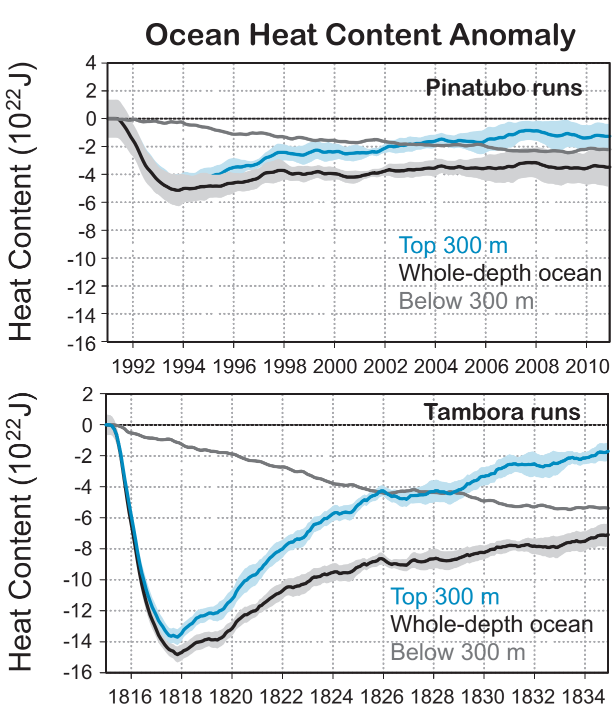

Figure 5. Ocean heat content after the Mt. Pinatubo and Tambora eruptions, modelled with CM2.1. From Stenchikov et al. (2009).

the Mt. Pinatubo eruption. However, the analysis of HALOE water vapour measurements suggests that the stratospheric water vapour was perturbed by the Mt. Pinatubo eruption. He further showed an increase in the vertical eddy heat flux in the tropical tropopause region. If models fail to capture this feature, they are likely to overestimate the temperature in this region.

C. Timmreck presented model results using ECHAM5 of the Mt. Pinatubo eruption, and SAGE II based stratospheric aerosols (Thomas *et al.*, 2009a,b). She discussed the hypothesis that volcanic eruptions could change the QBO. Sulphate aerosols forming in the tropical stratosphere lead to radiative heating and increase tropical upwelling, which possibly leads to upward advection of QBO winds, and a delay in the descent of the QBO phase. ECHAM5 shows that the polar night jet in the Northern Hemisphere is accelerated after the Mt. Pinatubo eruption; hence the Brewer-Dobson circulation in the lower and middle stratosphere was decelerated. However, with proper inclusion of sea surface temperature forcing and inclusion of a QBO in the simulation, the polar night jet is not strengthened.

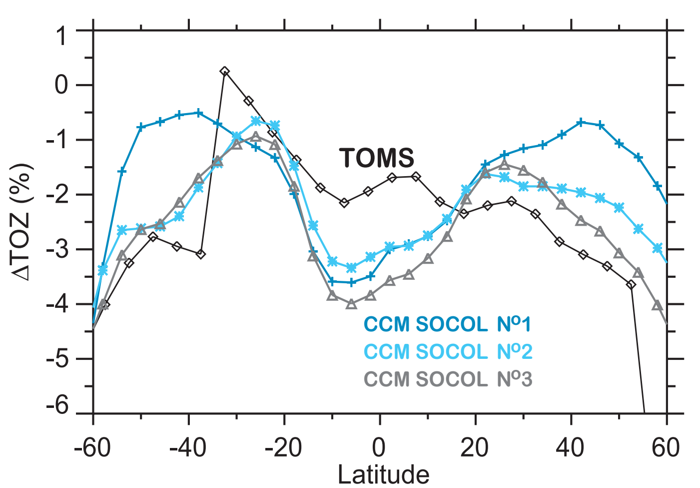

Figure 6. Zonal mean total ozone change averaged over the time period June 1991 - May 1993 with respect to June 1989 – May 1991 for TOMS satellite measurements and 3 ensemble runs of SOCOL. From E. Rozanov.

E. Rozanov showed Mt. Pinatubo simulations with SOCOL v2 (Schraner *et al.*, 2008). The model performance in simulating chemical effects is reasonable. Due to slightly underestimated SAD, the NO_x response is too small. Excessive tropical lower stratospheric warming leads to overestimation of the tropical ozone decrease (see **Figure 6**).

M. Mills presented a geoengineering study with enhanced OCS, as proposed by Budyko (1980), and simulations of Mt. Pinatubo eruption with WACCM/CARMA (Whole Atmosphere Community Climate Model 3 / Community Aerosol and Radiation Model for Atmospheres) (Mills *et al.*, 2008). The aerosol module CARMA resolves 38 aerosol size bins and is coupled to WACCM through the SAD, but without radiative feedback. According to their model simulation, the effects of enhanced halogen and reduced nitrogen ozone destruction cycles may compensate each other, while the enhanced hydrogen (HO_x) cycle leads to a net ozone decrease in such a geoengineering application.

Budyko (1977) and Crutzen (2006) proposed to inject SO_2 into the stratosphere to cool the Earth's surface. **A. Cirisan** showed a microphysical box model study using as input the aerosol size distribution produced by the AER aerosol model for geoengineering scenarios (Heckendorn *et al.*, 2009). Increased sulphate aerosols in the lower stratosphere due to geoengineering could affect the cirrus clouds in the underlying tropopause region. Geoengineering applications may lead to reduced cirrus ice crystal number densities, because the larger aerosol particles nucleate preferentially. This would lower the albedo of the cirrus clouds, partially offsetting the intended cooling effect.

Finally, **H. Graf** returned to the fundamental question whether the models were ready for a volcanic forcing. Many IPCC models have problems in simulating the observed surface pressure and temperature after large volcanic eruptions (Stenchikov *et al.*, 2006). Boer and Lambert (2008) showed that IPCC models in general simulate too vigorous an energy cycle. The models show a systematic model error of too-low upper tropospheric temperatures at high latitudes, which might be caused by the fact that the models generate excessive zonal available potential energy. Hence the models might reproduce the observations partly for the wrong reasons, and the dynamical feedbacks of the models could show deficiencies.

Additional remarks

One important discussion item during the meeting was the formation of a consistent stratospheric aerosol forcing data set that could be used by climate models. The gap-filling of SAGE II data was improved by Thomason and Peter (2006) in comparison to the one used in Russell *et al.* (1996) and Stenchikov *et al.* (1998). However, it could be further improved by using more data sets, for instance, from lidar airborne campaigns (*e.g.* Winker and Osborn, 1992a,b). The description of the volcanic aerosol distribution by a mono-modal lognormal distribution is not able to fully capture the volcanic forcing: either the SAD or the extinction will be wrong. Therefore, a new retrieval procedure fitting as many (extinction) measurements as possible to a bimodal lognormal-distribution is a promising way forward.

Another important discussion point was the following question: Are we ready for the next large volcanic eruption? If a large volcanic eruption were to occur in the near future with a strong impact on climate, the observational coverage would not be much better than it was for the Mt. Pinatubo eruption. In addition, if CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation) were to unexpectedly break down, the observational coverage would be even worse. The workshop participants agreed that better observations with more geographical coverage of volcanic eruptions would greatly improve the general understanding and model representation of volcanoes. Today little is known on the size distribution in the main aerosol cloud. It was suggested that all research groups should try to organise some extra resources to be able to enlarge the observational network for when a large volcano erupts in future. OPC measurements in the main aerosol cloud would be especially valuable. Another, cheaper option would be to launch several COBALD (Compact Optical Backscatter Aerosol Detector) instruments, which are lightweight backscatter sondes designed by Frank Wienhold (ETH Zurich) to be flown on operational weather balloons.

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Report on the SPARC data assimilation meeting at MOCA-09

Montreal, Canada, 19-29 July 2009

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Introduction

The SPARC–DA (Data Assimilation) working group was created in 2002 to coordinate and promote data assimilation work relevant to SPARC. The main vehicle for this activity has been annual dedicated workshops. Workshop reports are published in this newsletter, the most recent of which described the SPARC-DA and International Polar Year (IPY) workshop held in Toronto in September 2007 (see SPARC Newsletter No. 30). In 2009, we decided to try an experiment and co-locate the SPARC-DA meeting with the MOCA-09 (IAMAS, IAPSO and IACS) congress in Montreal in July since this meeting would have a large and diverse audience. The idea was to attract new participants in hopes of making this activity known to a wider audience. While the dedicated workshops highlight specific themes by inviting speakers to expound on selected topics, the MOCA-09 meeting consisted of two subsessions of contributed talks and posters within broader sessions: M01 (Middle Atmosphere) and J21 (Advances in Data Assimilation). In addition, a separate side meeting dedicated to the SPARC DA working group was held on the morning of Friday July 24. Here, the tradition of highlighting a theme was continued with three speakers having been invited to explore the topic of seamless prediction.

Seamless Prediction and Model error theme

Seamless Prediction is a broad term, generally referring to a unified framework for research on prediction in weather and climate, and it is a major theme of the WCRP Coordinated Observation and Prediction of the Earth System (COPES) strategic framework. Palmer *et al*. (2008) argue that reliable simulations of climate change require that climate models be capable of depicting processes on a wide range of time scales from years (forcing from cryosphere or biosphere) to seasons (ocean and land surface) to weeks (wave forcing) to one day (diabatic processes such as convection), and that any weak link in this chain will limit the accuracy of estimations of climate impact due to these forcings. Brunet *et al*. (2009) suggest various ways in which this seamless quality can be approached, including the use of data assimilation to identify climate model errors.

Because data assimilation involves a computation of the differences between short term (6h or 12h) model forecasts with measurements, indirect information about model error is routinely computed and archived at operational forecast centres. In addition, data assimilation methodology can be used to estimate uncertain parameters in climate models (instead of initial conditions). In the SPARC-DA meeting, the three invited speakers explored different methods of characterising model error.

C. Bishop (NRL) convened a separate session on seamless prediction (M07) and was invited to highlight stratosphere-relevant presentations from that session. He reported that only one presentation featured stratospheric issues. Y. Kuroda found that predictability of the tropospheric NAM index decreased both before and after the key day of a stratospheric sudden warming. This is an intriguing result as it is contrary to usual forecasting experience where shorter lead times lead to better forecasts. C. Bishop also described a method for flow adaptive ensemble covariance localisation that he felt might help ensemble DA schemes better reflect the fact that horizontal error correlation length scales are longer in the stratosphere than in the troposphere.

Because many of the uncertain parameters in climate models are associated with "fast" physics (such as deep convection), this type of model error also affects short time scale forecasts. **M. Rodwell** argued that the use of short time scale forecasts (and short time scale forecast tendencies) is a very efficient method of diagnosing such errors in fast physics. To motivate this point, Rodwell showed **Figure 1** (colour plate I), which compares 1-day and 10-day forecast errors of 500 hPa temperature averaged over the winter of 2007/08. 1-day forecast errors (top panel) show systematic errors that are statistically significant (deep colours indicate statistical significance) over the tropics, whereas 10-day forecast errors have a more complex spatial pattern with areas of statistically significant errors being reduced (even though error magnitudes increased). The argument is that after a few days, nonlinearity of the system creates nonlocal spreading of errors through scale interaction and chaos. Thus, the longer the forecast, the harder it is to connect its systematic errors with local sources of error. Rodwell demonstrated that initial forecast tendencies (within 6-hours) could be used to identify unphysical (and therefore unlikely) perturbations of a convection scheme associated with reduced turbulent entrainment. By identifying unphysical model perturbations, not only can individual models be improved, but a weighting scheme can be determined in which poorly conceived perturbations (or models) can be downweighted in ensemble predictions of climate uncertainty (Rodwell and Palmer, 2007).

A question that arises is whether this method can be applied in the stratosphere where the dominant errors are associated with wave forcing, radiation and chemistry interacting on longish time scales. In other words, is the basic hypothesis that time mean initial tendencies should average to zero valid when slow, small amplitude forcing can be expected such as with the tropical Quasi-Bienniel Oscillation?

Another method of improving climate models using data assimilation was presented by **M. Pulido**. Since climate simulations are sensitive to the "tuning" of Gravity Wave Drag (GWD) schemes (Alexander *et al*., 2009), it would be useful if an objective method of selecting parameters used in such schemes were available. Pulido showed that for a specific scheme (Scinocca, 2003), 1D variational techniques had difficulty due to the nonlinearity of the drag with respect to changes in parameters because complex cost function geometry with multiple minima were obtained. However, with a genetic algorithm, global solutions could be found and the resulting optimised parameters yielded drag profiles that matched observed profiles both in cases where observations were simulated with a perfect model or estimated using a 4D-Var technique (Pulido and Thuburn, 2008). **Figure 2** shows the observed drag field obtained using the 4D-Var technique (left panel) and the resulting drag obtained by the GWD scheme when the optimal parameters were used. The similarity of the fields suggests that the method is promising. However, important issues remain such as how to utilise the retrieved parameters. For example, in Figure 2, zonal mean drag profiles were used as "observations" when determining optimal drag parameters. Optimal parameters could have been obtained for each horizontal gridpoint, but is it better to obtain a set of parameters as a function of latitude only, or even a single global set of parameters?

16 Mesospheric Data assimilation and stratospheric winds

Now that mesospheric measurements such as those from TIMED-SABER and EOS-AURA-MLS have been available for a few years, stratopause structure can be studied on longer time scales than single stratospheric sudden warming events. **G. Manney** compiled a climatology of stratopause height covering nearly 4 years and compared the observed behaviour to analyses from assimilation systems with model lids at 0.01 hPa or higher: ECMWF, GMAO, CMAM-DAS and NOGAPS. Analyses generally captured the annual cycle in stratopause height in polar regions (high in winter, low in summer), but tended to have more difficulty in obtaining a low enough summer stratopause than the high winter stratopause. Operational analyses also missed the semi-annual signal in stratopause height in the tropics that was seen in the research products. NOGAPS products included the assimilation of SABER and MLS temperatures and were closest to the measurements. CMAM-DAS assimilated neither measurement source so its stratopause behaviour may be related to the high model lid and gravity wave drag depiction. Improvement in the GMAO tropical stratopause heights in October 2008 was obtained by removing bias correction procedures for

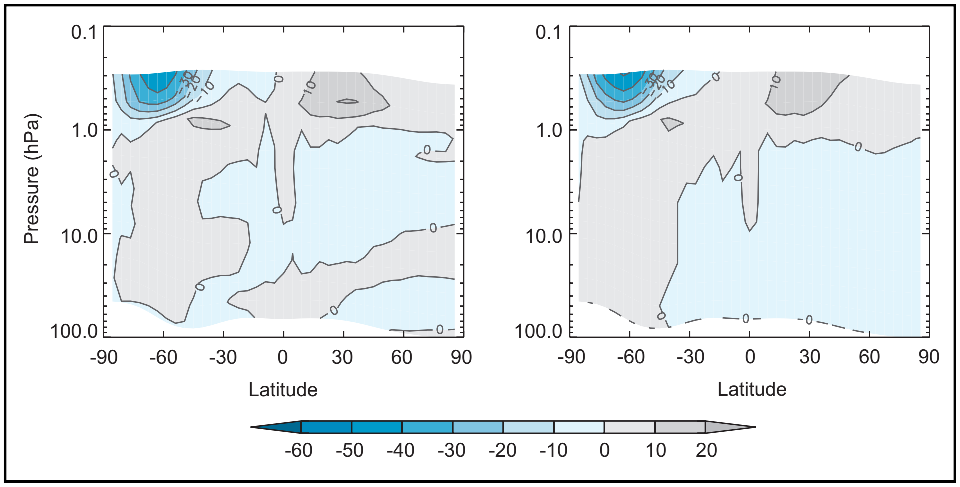

Figure 2: Missing zonal mean zonal drag for July 2002 due to unresolved waves estimated with a 4DVar assimilation system (Pulido and Thuburn, 2008) (left panel). The right panel shows the forcing from the Scinocca (2003) GWD scheme using the retrieved optimum parameters.

AMSU ch. 14, suggesting bias correction of observations may be harming analyses of the stratopause.

Y. Nezlin assessed the benefit of SABER temperature measurements in the context of perfect model experiments and found that temperature data helped improve large spatial scales and long time scales in the middle atmosphere. M. Keller further noted that when SABER temperatures are assimilated by CMAM-DAS, the mesospheric 2-day was captured but it was absent when no mesospheric measurements were assimilated. He also attempted to isolate the mechanism by which this signal was captured: whether directly through analysis increments or by improving the zonal mean temperature, which becomes baroclinically unstable.

In the future, new measurements of stratospheric winds are anticipated from the ADM-AEOLUS mission. Since information can propagate vertically, H. Körnich is considering the question of whether higher precision tropospheric or lower precision stratospheric sampling has a stronger impact on stratospheric wind analysis.

Chemical Data Assimilation

Chemical data assimilation is increasingly being used to infer information about the performance of model chemistry schemes. One example was given by **D. Jackson**. First, he showed how the UK Met Office ozone data assimilation may be used to estimate polar chemical ozone loss. This approach can have considerable advantages over other techniques (for example, better representation of model and observation errors, and of ozone loss outside the vortex) (Jackson and Orsolini, 2008, Sovde *et al*., 2009). The assimilation results were compared with results from the Oslo University CTM and the assimilation technique was able to highlight possible limitations in the CTM chemical scheme related to PSC modelling and the representation of NO after a solar proton event.

S. Polavarapu showed that assimilation runs made with CMAM-DAS highlighted model issues such as the partitioning of chlorine in the Arctic winter, even when no constituent data were assimilated. **J. de Grandpre** ran ozone data assimilation experiments at Environment Canada with different representations of ozone chemistry; one comprehensive (BASCOE), the other a simplified scheme (LINOZ). Although the BASCOE scheme better resolves ozone-temperature interactions than the LINOZ scheme, it was at the expense of creating stronger ozone biases, so clearly this emphasises the need to further examine the performance of the BASCOE scheme.

Y. Yang used the same model as de Grandpre (with BASCOE chemistry) to investigate the impact of assimilating MIPAS observations of O_3, NO_2, HNO_3 and $ClONO_2$ individually and in combination. The experiment was run during a period of high energetic particle precipitation (EPP), and one conclusion is that NO_2 and HNO_3 have to be assimilated to capture their anomalously high values seen during the EPP event. O_3 also needs to be assimilated, but the assimilation of $ClONO_2$ led to excessive destruction of O_3, indicating further tuning of the error variance and cross-correlation with other species needs to be taken into account. This study and that of Jackson showed the importance of assimilation in representing stratospheric constituent changes during geomagnetic events and the inability of current free-running models to represent them.

W. Lahoz attempted to bring studies, such as those listed above, together into a strategy for using data assimilation to evaluate and improve CTMs and CCMs, for example using multi-model assimilation CTM experiments to evaluate chemical parameters such as the onset of Cl activation, HOCl formation rate and ClOOCl photolysis.

An attractive feature of the EnKF is that, unlike variational schemes, it does not require a tangent linear model and its adjoint to propagate covariances, and therefore can retain the non-linear properties of the model used. In the stratosphere, this may be of particular benefit when representing strong non-linearity in wave-breaking regions and the coupling between ozone chemistry, radiation and dynamics. T. Milewski explored the application of the EnKF to stratospheric chemical-dynamical data assimilation. The EnKF was coupled with a coupled chemistry model that uses a fast interactive ozone scheme. Tests with explicit formulation of error covariances and observation localisation (after Houtekamer and Mitchell, 2001) showed satisfactory results, but using singular-value decomposition led to an unexplained divergence of the spread. Future work to diagnose this problem may include excluding chemical tracers from the state vector, or using a larger ensemble.

Other related talks focused on both troposphere and stratosphere. M. Deushi described initial work to develop an EnKF assimilation system for the Japanese MRI CCM (which is designed to simulate ozone and related chemical species in the troposphere and middle atmosphere). First results are encouraging. **K. Miyazaki** applied a variant, the local ensemble transform Kalman Filter (LETKF), to CO_2 in the troposphere. No chemistry was included, but the representation of surface fluxes was, and the results showed the ability of the assimilation scheme to correct errors in surface fluxes. This was largely a simulation study aimed at showing the usefulness of the CO_2 assimilation, but in the future the scheme may be used to assimilate actual observations (*e.g.* from GOSAT).

Two talks focused on the ability of data assimilation schemes to represent small scales. **I. Stajner** performed one such study focusing on ozone assimilation performed with a relatively coarse resolution model (1 deg x 1.25 deg), and using satellite, but no *in situ*, observations. Comparison with troposphere / lower stratosphere ozonesonde data showed good agreement at larger spatial and temporal scales, which perhaps represents the limitations of model and observations used in the data assimilation system. A more detailed power spectrum analysis against MOZAIC data showed that the data assimilation corrects larger scale, but the forecast model drives smaller scales (there is little evidence that the smaller scales are smoothed in the assimilation).

V. Yudin introduced the concept of resolution dependent analysis. The idea is to directly constrain only those forecast scales that are resolved by observations. The optimally defined averaging kernels help to describe the spatial resolution of measurements. These highlight observable and non-observable scales for each observation type, and can be used to separate analysis increments into components attributable to these observable and non-observable scales. He was able to show that the latter contributed to biases in the inversion of satellite radiances. More generally, it appears that using optimally-defined resolution kernels in the observation operators can lead to errors that are scale-dependent, with no smearing of non-observable scales, and can lead to optimal vertical mapping of space-borne observations onto model space that adequately reflect the physics of the observations.

Developments in air quality and aerosol assimilation have traditionally tended to lag behind those in other areas of atmospheric assimilation, but two talks showed the considerable progress that has been made in these areas in recent years. **H. Elbern** used 4D-Var to estimate surface emissions and the tropospheric chemical state. He pointed out that as well as initial conditions and emissions, other uncertainties include deposition/sedimentation rates, boundary layer height and convection, so it is not an easy subject, leading him to pose the question: is air quality assimilation mature yet? Certainly, the estimation of emission rates appears feasible, although there are issues with the optimisation of tropospheric column information for successful surface observation validation, which suggests that an investigation of this topic using the resolution based analysis proposed by Yudin may be fruitful.

J-J. Morcrette discussed the GEMS system developed at ECMWF. The aerosol model has 12 prognostic variables including dust, sea salt, black carbon, organic and sulphate. Near-real time MODIS aerosol optical depths at 550 nm were assimilated. An issue with the MODIS data is that it is not able to distinguish between aerosol types, so the 12 prognostic variables are merged into one "total aerosol" variable for the assimilation and the analysis increment is partitioned amongst the 12 types according to the background values. Despite this potential limitation, the GEMS system shows good results in comparison with AERONET observations and is able to represent Saharan dust outbreaks reasonably well.

IPY update

The International Polar Year (IPY) ran from March 2007 to March 2009. Thus, the SPARC-IPY data archive is now nearly complete. The archive of analyses currently contains dynamical variables and some constituents from operational and research assimilation systems: ECMWF, NCEP, Met Office, GMAO, UKMO-UARS, CMAM-DAS and GEM-BACH and is publicly available from the SPARC Data Center. **N. McFarlane** mentioned the possibility of adding a new set of analyses from BASCOE/PROMOTE (PROtocol MOniToring for the GMES Service Element). If included, this would be the first in the archive to have assimilated constituent measurements. Characterisation of both Arctic and Antarctic stratospheres during IPY has begun with articles such as those published in SPARC Newsletter No. 33. In addition, outreach activities include a popular science article in an inflight magazine by E. Farahani entitled "Have We Forgotten about Ozone in the Climate Change Era? Maybe Not!" With the end of IPY, the SPARC-IPY project also draws to a close but a few issues remain, the most critical being how to maintain the SPARC-IPY website and archive.

Discussion of format

As this was the first SPARC-DA meeting held within a larger, multi-session conference, it is worth reviewing the advantages and disadvantages of this format. As noted above, the goal was to expose new people to the SPARC-DA working group, particularly those who might not take the time to come to a dedicated SPARC-DA workshop. From attendance lists taken during the dedicated SPARC-DA side meeting, a few new people were noted. However, there were a number of problems with the format. The main issue was competition with parallel sessions. For example, the M01 (Middle Atmosphere) data assimilation session was parallel to the M07 (Seamless Prediction) session, which was primarily data assimilation. Also the SPARC-DA side meeting was parallel to two sessions of stratosphere-troposphere coupling and a data assimilation session. As a side meeting, it was also not very visible in the program. As a result attendance at the SPARC-DA meeting was poor, varying from 35 (during invited talks) to 10 (during the discussion). The issue of parallel sessions is common to all large congresses and worked against the goal of attracting new participants. In addition, the discussions are an integral part of the SPARC-DA meetings but cannot compete against parallel sessions. As a result, SPARC-DA participants generally felt that the dedicated workshops work better.

Next meeting

The next SPARC-DA workshop will be held at the Met Office in Exeter, England during 21-23 June 2010. Possible themes for the workshop include estimating model error, mesosphere-stratosphere-troposphere coupling and air quality and aerosol assimilation.

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The Stratosphere-Troposphere Analyses of Regional Transport 2008 (START08) Experiment

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Introduction

It is recognised that the region near the tropopause (the upper troposphere/lower stratosphere (UTLS)) plays an important role in the chemistry and dynamics of the atmosphere. The tropopause region is typically characterised by large gradients in trace gases and water vapour, and by significant changes in dynamical properties between the troposphere and the overlying stratosphere. Transport and exchange of air masses between the troposphere and stratosphere influence the distribution and fate of trace gases and aerosols in this region. Because the distribution and abundances of water vapour, ozone, aerosols and cloud particles contribute significantly to the radiative budget of the planet, processes that affect these distributions and abundances can play a role in climate regulation. Accurate representation of chemical features of the tropopause region, and accurate represention of the underlying dynamical processes, is a challenge to the current generation of global chemistry-climate models. Appropriate measurements within the tropopause region provide a basis for evaluating and diagnosing such models. Such measurements are commonly made from various platforms, including satellites and sondes, but *in situ* measurements from airborne platforms can provide high-resolution detail over a range of spatial scales. The need for such measurements and the availability of a new airborne research capability motivated the research campaign that is discussed here.

The Stratosphere-Troposphere Analyses of Regional Transport 2008 experiment (START08) was sponsored by the US National Science Foundation to investigate chemical and dynamical processes in the UTLS (Pan *et al*., 2009) Specifically, the experiment focused on the extratropical UTLS. The campaign was conducted during April to June, 2008, from Broomfield, Colorado, using the NSF Gulfstream V (GV) research aircraft. A total of 18 research flights sampled an extensive geographical region of North America (25-65°N and 80-120°W), from boundary layer to ~14.5 km (**Figure 1,** colour plate I). A total of 18 *in situ* and remote-sensing instruments for chemical and microphysical measurements were deployed, and represented the most complex chemistry payload carried by this relatively new research aircraft (**Figure 2**). The high-resolution model forecasts that were used for flight planning allowed the large suite of chemical, dynamical, and microphysical measurements to target specific meteorological conditions. This article provides a brief overview of the experiment including scientific objectives, experiment design, selected highlights and ongoing research activities.

Scientific Objectives

The primary research objective of the START08 mission was to characterise the contribution of transport processes to the chemical structure of UTLS region. A main hypothesis was that measurements of chemical distributions in well-defined meteorological conditions could be used to identify and characterise tracer signatures that are associated with key transport processes in the region of the extratropical tropopause. This general objective was pursued in an airborne research campaign that targeted specific transport pathways and mixing regimes. Data collected during the campaign will be followed by analyses combining *in situ* observations with satellite data, and regional and global model simulations.

Broadly, the scientific questions that were investigated during the experiment were:

1. What is the behaviour of the extratropical tropopause as a transport boundary? In the absence of dynamical stirring, the extratropical tropopause behaves like a relatively sharp material boundary and separates stratospheric and tropospheric air. On the cyclonic side of the subtropical jet, the thermal tropopause is often less distinct; the thermal and dynamical tropopause definitions often produce very different tropopause heights. Associated with this difference is significant mixing of stratospheric and tropospheric air that leads to the formation of an extratropical transition layer (ExTL) in the region. The depth of the ExTL is not uniform, and is a result of combined large-scale stirring and small-scale turbulence. While small-scale turbulence contributes to mixing in the transition layer, the vertical depth of the layer is dictated by the occurrence and frequency of large-scale disturbances, such as wave breaking, and synoptic scale events, such as tropopause folding along upper level frontal zones. These processes should result in a signature in the chemical tracer distributions in the ExTL that can be measured and quantified. The microphysical environment of the ExTL is unique and under certain conditions, suitable for ice cloud formation.

2. What are the chemical signatures associated with the key dynamical processes that couple the UT and LS? A main objective of the START08 experiment was to investigate the chemical and microphysical characteristics of the air masses in the major transport pathways that couple the UT and LS. Combining tracer measurements with a set of models, we hoped to explore some of the following issues.

1) *Ozone in the UTLS:* The LS has maximum ozone loading in the spring season. Coupled with the active adjustment of tropopause height during spring (from a low winter tropopause to a higher summer tropopause), stratospheric influences on the UT are largest in spring. There should be higher ozone values, compared to those in winter, associated with the air mass in the 2-4 PVU range; previous observations in winter show that this air mass is the part of UTLS that is involved in irreversible exchange.
2) *Tropospheric intrusions:* Large-scale quasi-isentropic mixing by breaking waves is inhibited near the core of the subtropical jet (Bowman, 1996; Haynes and Shuckburgh, 2000; Rypina *et al*., 2007). Above the jet, however, wave breaking moves low ozone air poleward from the tropics to produce the extratropical minimum seen near 400 K.
3) *Microphysics in the UTLS:* The humidity reached in the frontal zone is often suitable for formation of ice particles *via* homogeneous nucleation. The frontal lifting may also serve as a transport pathway for mass transport of ice particles into the stratosphere.
4) *Effect of convection:* Deep convection is a major perturbation to composition and chemistry in the UTLS, with a complex interaction of gas-phase chemistry, aerosol microphysics, and cloud dynamics. We expect that observations of "fresh" outflow will show that convection is a significant perturbation to the chemical budget in the ExUTLS at this time of the year.

3. What is the role of gravity waves in the structure and composition of the ExUTLS? Tropopause jets/fronts are significant sources of gravity waves (GWs)

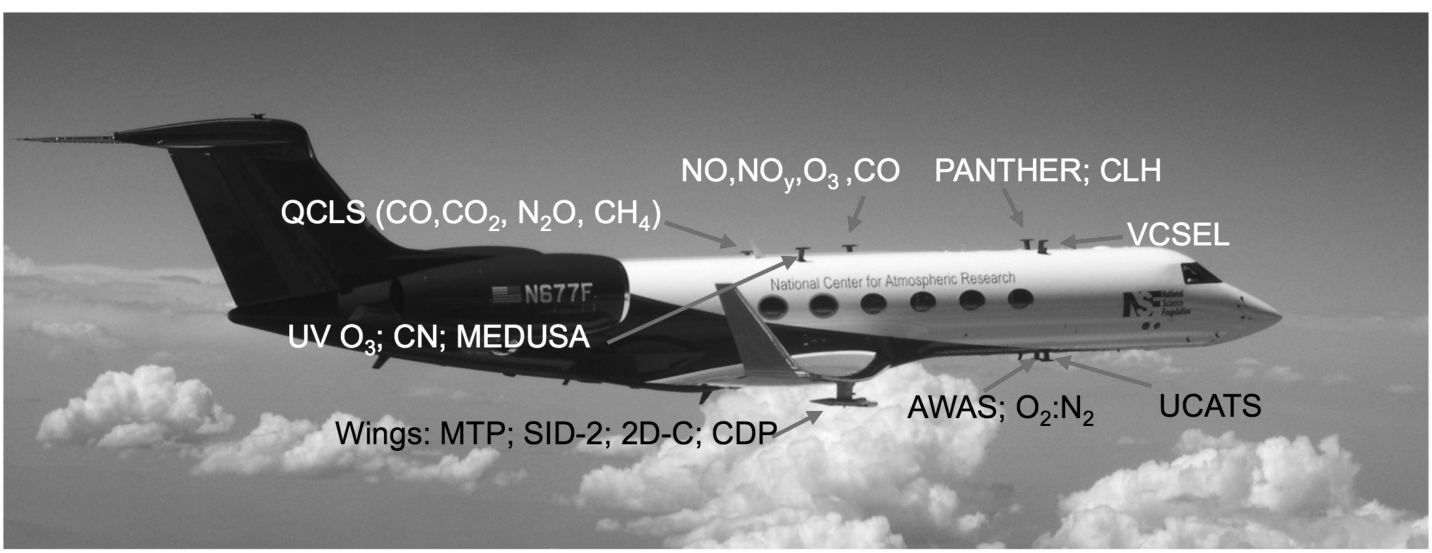

Figure 2. View of the NSF Gulfstream V aircraft taken during an airborne intercomparison exercise. Locations of instrument inlets and external probes are indicated.

(Reeder and Griffins, 1996; Zhang, 2004; Wang and Zhang, 2007). GWs above the jet may be responsible for double or multiple tropopauses (Yamanaka *et al*., 1996; Pavelin *et al*., 2001) and may contribute to layered ozone or PV structures (Bertin *et al*., 2001). Also, the strong horizontal and vertical shear, and strong discontinuity in static stability in the tropopause region provides a favourable environment to capture GWs generated in the lower troposphere, such as those produced by topography and surface fronts (Plougonven and Snyder, 2006). Regions of strong vertical/horizontal shear are also preferred environments for wave breaking. GW breaking and/or wave-induced turbulence (*e.g*. Koch *et al*., 2005) can contribute significantly to mixing of trace gases in and near the ExTL region, thereby affecting chemical composition (Vaughan and Worthington, 2000). Also, convectively generated GWs may extend the impact of moist convection far above cloud tops (direct injection/transport) through wave mixing/transport due to breaking and wave-induced turbulence (Lane *et al*., 2004). We hope to assess how well the current generation of mesoscale models can predict the excitation of GW by jet/fronts.

Instrument	Measurements	Institute
Chemical Tracers		
Advanced Whole Air Sampler (AWAS)	Multiple trace gases	HAIS/University Miami
Quantum Cascade Laser System (QCLS)	CO_2, CO, CH_4, N_2O	HAIS/Harvard University
Fast-Ozone (FastO3)	O_3	HAIS/NCAR
Total Reactive Odd-Nitrogen and Nitric Oxide	NO_y, NO	NCAR
Dual-Beam UV Absorption Ozone Photometer	O_3	NOAA/ESRL/CSD
VUV resonance fluorescence	CO	NCAR
Open Path Tunable Diode Laser Hygrometer	H_2O vapour	NCAR
Vertical Cavity Surface Emitting Laser Hygrometer (VCSEL)	H_2O vapour	HAIS/SWS
Unmanned Aircraft Systems (UAS) Chromatograph for Atmospheric Trace Species (UCATS)	H_2O, O_3, N_2O, SF_6, H_2, CH_4, CO	NOAA/ University of Colorado
PAN and other Trace Hydrohalocarbon ExpeRiment (PANTHER)	Multiple trace gases	NOAA
Airborne Oxygen Instrument (AO2)	O_2:N_2	NCAR/RAF
Multiple Enclosure Device for Unfractionated Sampling of Air (MEDUSA)	O_2:N_2, Ar:N_2, $^{13}CO_2$, $C^{18}OO$	NCAR/RAF
Cloud Microphysics		
Closed-path tunable diode Laser Hygrometer (CLH)	Total Water	University of Colorado
Small Ice Detector-2H (SID2)	Small ice (2-60mm)	HAIS/NCAR
Two-D cloud particle imaging probe (2DC)	Ice + rain (25-1600 mm)	NCAR/RAF
Cloud Droplet Probe (CDP)	Cloud drop (2-60 mm)	NCAR/RAF
Condensation nuclei (water-CN)	Condensation nuclei	NCAR/RAF
Remote Sensing		
Microwave Temperature Profiler (MTP)	Temperature profile	HAIS/ JPL

Table 1. Instrument payload on the NSF Gulfstream V aircraft during START08.

Payload and measurement strategy

The capabilities of the NSF/NCAR GV research aircraft were demonstrated during the START05 experiment in December 2005 (Pan *et al*., 2007), shortly after the aircraft arrived at NCAR. This experiment, with a limited payload, showed the GV to be ideally suited for investigating the extratropical tropopause region. Even with the more comprehensive START08 payload, the GV could reach 47 000 ft (~14.3 km), which is well above the typical extratropical tropopause. This altitude capability allowed us to map chemical gradients across the tropopause and follow the gradient well into the lower stratosphere. Furthermore, the long flight duration (~8 hr) enabled the GV to provide high-resolution *in situ* observations of synoptic-scale chemical and dynamical structures, and to make observations during long-range surveys.

In addition to the standard aircraft state measurements, the START08 payload carried a reasonably comprehensive suite of instruments for trace gas chemistry and aerosol microphysics (**Table 1**). The START08 mission also shared common instrumentation and scientific objectives with the HIPPO (HIAPER Pole-to-Pole Observation) mission, which needed to test instrumentation under typical flight conditions prior to its global survey planned for 2009 and later years.

The chemical and microphysical instrumentation addressed multiple objectives. Ozone, water vapour and CO have been demonstrated as effective tracers for identifying the chemical transition across the tropopause. SF_6 and CO_2 have been widely used to diagnose the age of air in the stratosphere through comparisons with well-defined tropospheric temporal trends. Additional long-lived tracers (CH_4 and N_2O), and tracers of different lifetimes and latitudinal gradients (NMHC, halocarbons, HCFCs, *etc*.) from the Whole Air Sampler and PANTHER instruments, are used to examine the influence of different transport pathways and to evaluate age distributions in the ExTL. The addition of the airborne GV systems added valuable information by providing higher time resolution for selected species also measured by the Whole Air Sampler. Nitric oxide and total reactive oxidized nitrogen (NO/NOy) provide information about the impact of pollution, aircraft emissions and lightning sources of reactive nitrogen (and related species) to the UTLS.

The O2:N2 ratio instrument addressed a high priority for HIPPO – to help interpret measurements of carbon cycle gases, but the data in the UTLS provide new and intriguing high precision measurement of stratospheric O2:N2 variations. These variations were recently reported from balloon-borne measurements (Ishidoya *et al*., 2006), but at lower precision than those measured *in situ* during many of the START08 flights. The MTP measures temperature profiles that provide the tropopause height along the flight track, and map out the vertical thermal structure of the UTLS region. For the microphysics studies, water vapour, total water, and ice particle measurements over the size range of 2-1600 µm were made.

Flight Scenarios and Planning

In preparation for the mission, meteorological conditions from previous years were evaluated to plan flight strategies that could address the scientific objectives for START08 and preHIPPO. These evaluations led to a set of prioritised flight scenarios which could be chosen, modified, and combined for the conditions that were encountered during the experiment. The menu of flight scenarios that were developed were:

- UTLS Survey - to obtain constituent distributions and tracer relationships across the tropopause for a range of thermal and dynamical conditions
- Stratospheric Intrusion - to investigate stratospheric influence on the troposphere, and mixing and irreversible transport during tropopause folds
- Tropospheric Intrusion - to study the origins and fate of air with tropospheric characteristics in the LS
- Convective influence - to investigate UT tracer distributions influenced by convective transport and lightning, and to explore flight strategies for measuring the influence of storms
- Cirrus layers - to examine cirrus cloud layers near the extratropical tropopause
- Gravity waves - to observe the properties of gravity waves generated by multiple sources, including jets/fronts and topography
- PreHIPPO - to test instrument and aircraft performance while profiling from the boundary layer to the tropopause, a strategy needed for the Global HIPPO project.

Each of the 18 flights was planned around one primary objective but often contributed to additional objectives. During the mission, most of the flight scenarios were used during multiple research flights (except for the gravity wave objective, which was addressed with only one dedicated flight).

Forecasting and flight planning were supported with multiple models. The primary model for flight planning was the NCEP Global Forecast System (GFS) converted from its native-grid resolution of T382L64 into 0.325° by 0.325° at 47 pressure levels. For this mission we used twice-daily forecasts (00Z and 12Z) out to 54 hours. Customised tools for interactively displaying cross-sections of the GFS model were developed by the team to visualise the tropopause structure, jet position, PV and intrusions. The GFS ensemble forecasts were used for longer-range logistical planning. In addition, high-resolution Advanced Research WRF (Skamarock *et al*., 2005) forecasts were produced at Texas A&M (one 15-km resolution run and a 45-km resolution ensemble initialised with a mesoscale ensemble-based multi-physics data assimilation system; Meng and Zhang, 2008a,b) and NCAR (20-km resolution run initialised with GFS analysis) to provide additional guidance. Nowcasting was provided to the on-board mission scientist to support in-flight decisions.

Observation Highlights

Next we present a brief discussion of several examples related to different mission objectives. Examples include tracer correlations and distributions from research flight 1 (RF01), which investigated a tropospheric intrusion event, and research flight 4 (RF04), which focused on a stratospheric intrusion event. Research flight 14 (RF14) provides an example of convectively–influenced air, and research flight 2 (RF02) observed episodes of jet-generated gravity waves.

a. Tracer correlations: Tropospheric intrusion, RF01, 18 April 2008 and Stratospheric Intrusion, RF04, 28 April 28 2008

START08 missions looked in detail at two of the major pathways of exchange: Troposphere to Stratosphere Transport (TST - Tropospheric intrusion) and Stratosphere to Troposphere Transport (STT - Stratospheric Fold). Evidence of subtropical tropospheric air deeply intruding into the high latitude lower stratosphere has been observed as low ozone laminae in the ozonesonde data for several decades (Dobson, 1973; Vaughan and Timmis, 1998). Only recently has it been unambiguously identified, using satellite data and high-resolution meteorological analyses, that these low ozone laminae are part of stratified structures associated with the occurrence of the secondary (double) tropopause (Pan *et al*., 2009). Furthermore, analyses based on newly available, near-global coverage by space-borne GPS measurements indicate that double tropopause events are much more extensive than previously documented (*e.g*. Schmidt *et al*., 2006; Randel *et al*., 2007).

The second major pathway of exchange occurs through stratospheric intrusions in the form of tropopause folds. These are well-known events that bring high ozone air into the upper (and even lower) troposphere (Danielsen, 1968). Since dynamical variables, such as PV, and chemical variables, such as ozone, may not have the same lifetime in the tropopause region, meteorological analyses alone are not able to quantify the impact of folding events on the chemical structure of the UTLS. The START08 mission was able to map the chemical structure of stratospheric intrusions using the large suite of tracer instruments on the GV.

Two flights provide excellent examples of the tracer characteristics associated with these major transport pathways. **Figure 3** (colour plate II) shows the O_3:CO correlations from these two flights (RF01 and RF04). While both tracer correlations show mixing associated with the subtropical jet during each flight, only RF01 shows the clear signature of tropospheric air penetrating into the high latitude stratosphere near the 380K potential temperature surface.

Since characterisation of tropospheric intrusions was a major emphasis of the START08 mission, forecasts of tropospheric intrusions were made using high-resolution GFS data and the method demonstrated in Pan *et al*. (2009). Based on this type of forecast, the first flight of the mission was designed to reach the region of a major tropospheric intrusion. A triangular flight path with several vertical profiles was followed to sample the vertical and horizontal gradient of the air mass associated with the intrusion. **Figure 4** (colour plate II) shows the first leg of the GV flight track and the vertical section of the static stability (dq/dz) along track, which went northeastward from Colorado to near the shore of Hudson Bay. The cross-section of the static stability shows a layered structure with two stable layers, one near 300 hPa, associated with the primary tropopause, and one above 100 hPa, associated with a secondary tropopause. The layer of low stability air in between is centred about 150 hPa (~ 14 km altitude, 380 K potential temperature). This was near the GV service ceiling for this mission. The vertical gradient of trace species was measured for the altitude range from the upper troposphere to the centre of the low stability layer. The primary tracers, ozone and CO, are consistent with the dynamic variables in GFS analyses, showing a sharp increase of ozone as the GV entered the stratosphere which immediately dropped back to near tropospheric levels in the low stability layer. The behaviour of the tropospheric tracer, CO, was opposite to that of ozone, as expected. Together, the data reveal anomalous values of ozone (~150 ppbv) and CO (~ 50 ppbv) at 380 K near 50°N.

Other tracer measurements (not shown here) further characterise the layer with an "age" of only several months, and composition similar to that found in the tropical tropopause region. To further support the recent entry of air into the stratosphere, significant levels of relatively short-lived organic gases were measured in the intrusion layer. The subsequent question is how often and to what extent this type of event perturbs the chemical composition of the LS.

22 The example of characterisation of a tropopause fold is shown with Flight RF04. This flight targeted a stratospheric intrusion event associated with a long narrow trough over the central US. The meridional polar jet accompanying this sharp trough merged with the subtropical jet over Mississippi and Alabama. In **Figure 5** (colour plate III) the fold can be seen as the 2 PVU potential vorticity surface (purple) intruding underneath the jet (blue). The aircraft made several transects across the jet and the fold at different altitudes at approximately 40°N. Several complete profiles from ~ 3 km to ~ 14 km were made to map out the chemical gradient on both the cyclonic and anticyclonic side of the jet. In the region of the fold, the thermal tropopause (yellow) is widely separated from the 2 PVU surface, reflecting a weak thermal gradient in the region. The correlation between ozone and CO further indicates that a broad layer of mixed stratospheric and tropospheric air exists in the region of the fold. The stratospheric intrusion is therefore responsible for broadened extratropical transition layer (ExTL) (WMO, 2003), a region strongly influenced by mixing.

b. Convective influence, RF14, 18 June, 2008

Thunderstorms alter the chemical composition of the UT and sometimes the LS through rapid vertical transport of insoluble constituents from near the boundary layer, and through production of NO during lightning discharges. The extent and variety of constituents added to the UT will depend on at least the proximity of the thunderstorm to boundary layer pollution or to locations of strong biogenic emissions, and on the frequency and strength of lightning activity. Additions of NO from lightning and aircraft, or vertical transport of other precursors to peroxy radical formation are a significant source of ozone production in the UT on regional and global scales (*e.g.* Pickering *et al*., 1998; Cooper *et al*., 2007, Hudman *et al*., 2007).

Flight RF14 allowed limited sampling of a highly electrically active Mesoscale Convective System (MCS) that extended over North Dakota and southern Manitoba. **Figure 6** (colour plate III) shows that the GV descended from 14 km into the storm clouds to just below 9 km where conditions became sufficiently turbulent, as indicated by the vertical wind variations from ~ +6 m/s to -10 m/s, that the GV ascended to its original altitude above the complex. Figure 6 also shows that during the dip in altitude into the storm, enhancements in NO of up to 4-7 ppbv were observed between 9 and 10 km due to lightning activity. These enhanced mixing ratio are comparable to observations of lightning production of NO made in thunderstorm studies over the US midwest (Dye *et al*., 2000), but not as large as observed in some storms over Florida (Ridley *et al*., 2004b).

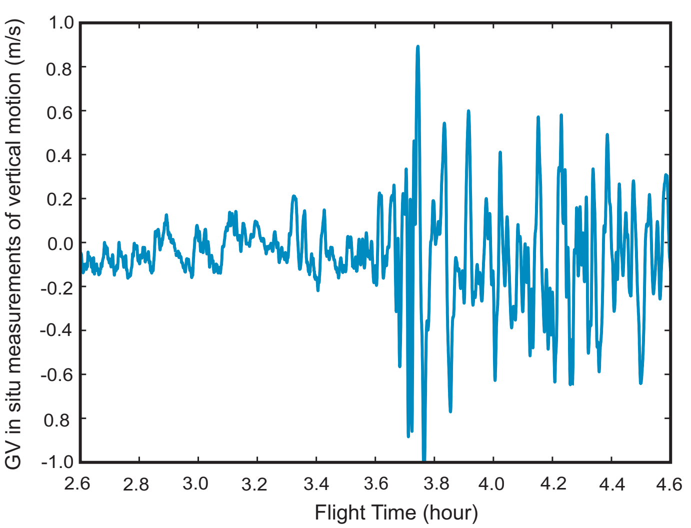

Figure 7. Time series of vertical velocity showing the presence of gravity waves measured during START08.

In situ tracers also provided signatures of convective transport. In the centre of a convectively influenced air mass, low CO_2 is the result of biogenic uptake of CO_2 in the boundary layer and subsequent rapid vertical transport. Similarly, many short-lived gases with surface emissions and normally low mixing ratios in the UT were found to be significantly enhanced within the convective updraft. As an example, methyl iodide (lifetime ~ 4 days) is shown here. Finally, ozone variations reflect the complex flow around the convective system that influence UT composition. Higher ozone at the boundary of the convective cloud suggests entrainment of air from the LS, while the central convective updraft results in low ozone, typical of boundary layer input.

c. Gravity Waves, RF02, 21 April, 2008

Gravity waves (GWs) are known to play an important role in the UTLS. *In situ* measurement of terrain-induced GWs in the extratropical UTLS region was a focus of a previous campaign with the GV aircraft (Grubišić *et al*., 2008), but the role of jets and fronts in GW generation is not well understood (Zhang, 2004). Systematic observations of jets and fronts as GW sources do not exist. One goal of START08 is to test how well the current generation of mesoscale models predict the excitation of GWs by jets and fronts (Wu and Zhang, 2004), and what tracer measurements can contribute to our understanding of GW breaking in the UTLS (Koch *et al*., 2005).

Flight RF02 on 21 April 2008 focused on GW excitation from both jet/front and topography. The flight track (not shown) operated near 10 – 13 km and followed regions where GW generation was predicted by the real-time mesoscale analysis and forecast system using the Advance Research WRF model (Skamorock *et al*., 2005) and an ensemble-based multi-physics data assimilation (Meng and Zhang *et al*., 2008a,b). The GV-measurements of flight-level vertical motions show significant GW activity with wavelengths ranging from 10 to 300 km. These wave signatures are present in almost every leg of the 8-hr flight, mostly in the LS. **Figure 7** displays a 2-hr segment of the flight. Initial analysis shows that the mesoscale component of the GW measured during the flight had qualitative agreement to those predicted by the 15-km mesoscale model. This result represents the first successful mesocale model prediction and high-resolution *in situ* measurement of these types of gravity waves by a research aircraft. Future work will examine the origin, dynamics and impacts of these gravity waves.

Summary and Outlook

The START08 experiment succeeded in mapping chemical distributions, variations, and relationships associated with major transport pathways in the UTLS region and in defining the different chemical gradient across "flat" and "structured" tropopause regions. The deep intrusion of tropospheric air into the lowermost stratosphere associated with the secondary tropopause is among the processes that are observed *in situ* for the first time with an extensive chemistry payload. The data analyses and modelling of the observed events should bring new insight into the mechanisms that control the chemical composition of the UTLS. Chemical tracers with different emission regions and with a wide range of lifetimes were sampled under a wide range of meteorological conditions during START08. These measurements make the START08 data set a significant asset for quantifying time scales of the relevant transport processes, and help connect meteorological fields to the underlying chemical composition. The suite of tracers also presents a unique opportunity to characterise the chemical age and age spectra (*e.g.* Schoeberl *et al*., 2005) of the UTLS region under different conditions. Age spectra and age-of-air characterisation have been useful diagnostics to evaluate stratospheric transport in large-scale models (Waugh and Hall, 2002 and reference there in). The measurements from START08 provide the opportunity to extend these diagnostics to shorter time scales, especially for the UTLS, a region of active stratosphere-troposphere interactions (*e.g.* Ehhalt *et al*., 2007; Scheeren *et al*., 2003).

Detailed comparisons of model and observations, along with process studies, will be major components of the post campaign analyses. A planned inter-comparison of model simulations from WACCM and CLaMS, one in Eulerian and one in Lagrangian framework, will examine the strengths and weaknesses of each framework in representing the tracer structure in the tropopause region and the mixing process for different dynamical conditions. Moreover, high-resolution cloud-resolving simulations with the Advanced Research WRF model will be used to explore the dynamics and impacts of smaller-scale processes such as gravity waves, convection and turbulence in the UTLS region.

With the extensive spatial coverage and dynamical conditions sampled, START08 data make a strong addition to an aircraft-based UTLS trace gas climatology (Tilmes *et al*., 2009). The statistical characteristics of UTLS chemical constituents will be an important reference for chemistry-climate models, and for validating satellite data. These are among a wide range of problems the START08 team and collaborators will pursue as part of the post campaign research activities. The START08 team welcomes collaborations in data analyses and the data are open to the research community. To access data, use the following link: **http://www.eol.ucar.edu/projects/start08/START08_HomePage.html**.

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The EU project SHIVA (Stratospheric ozone: Halogen Impacts in a Varying Atmosphere)

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Introduction

The recent WMO assessment of stratospheric ozone (WMO-2007) revealed growing evidence that the halogen loading of the stratosphere is partly controlled by the influx of so-called halogenated Very Short Lived Substances (VSLS) and their inorganic degradation products, *i.e.* halogen bearing inorganic gases (PGs) and aerosols. Most evident is their contribution to stratospheric bromine for which the recent WMO assessment (2007) indicated a source fraction of about 25 % (3 – 8 ppt, most likely 5 ppt) from VSLS (**Figure 1**).

Recent measurements of total stratospheric chlorine in air collected within the tropical tropopause layer/lowermost stratosphere (TTL/LS) indicates that VSLS and their inorganic PGs are less important contributors to total chlorine (1 – 2%) (*e.g.* Laube *et al.*, 2008). In contrast, iodinated VSLS and PGs, and iodine tied to aerosols are presumably the main sources for stratospheric iodine. However, the role of iodine in destroying stratospheric ozone is thought to be small due to their low concentrations, summing up to several 0.1 ppt in the TTL/LS at most (*e.g.* Murphy *et al.*, 2000; Butz *et al.*, 2009).

Figure 2 (colour plate IV) (adopted from WMO, 2007) displays the most relevant processes that determine the contribution of VSLS, PGs and aerosols to total stratospheric halogen. Halogenated VSLS are known to have the largest sources from a marine environment with high biological activity, such as the warm waters in the Tropics (*e.g.* the warm pool of the Western Pacific and the tropical Atlantic), oceanic regions of upwelling waters (*e.g.* off the coast of Africa or South America), local pollution or river deltas where prominent rivers discharge their waters into the ocean (*e.g.*, Amazon, Nile, Ganges, Yungste), and biologically productive coastal regions.

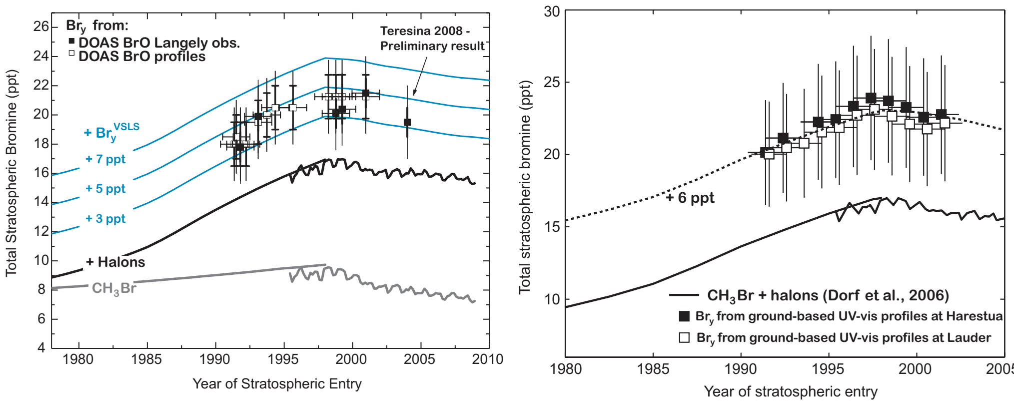

Figure 1 (left panel): Trends (solid lines) of expected total inorganic stratospheric bromine (Br_y) due to measured tropospheric abundances of bromine from methyl bromide (CH_3Br; gray lines), the sum of CH_3Br plus halons (black lines), together with assumed additional bromine (3, 5, and 7 ppt) derived from VSLS and/or inorganic tropospheric bromine sources (thin blue lines). The gray and black lines prior to 1995 are based on a combination of Antarctic firn air reconstructions and ambient air measurements, adjusted to represent mean global abundances, and updated here with mean ambient air measurements (post-1995) from NOAA global monitoring stations (Montzka et al., 2003). The squares are total inorganic bromine derived from stratospheric balloon measurements of BrO and photochemical modelling to account for BrO/Bry partitioning. The filled black squares are from Langley plots of total BrO measured above balloon float altitude, the open squares are lowermost stratospheric BrO measurements (Dorf et al., 2006, together with more recent data). Bold/faint error bars correspond to the precision/accuracy of the estimates, respectively. (right panel): Trends in stratospheric Br_y annual means at Harestua (60° N, 10° E) and Lauder (45°S, 170°E) and bromine long-lived source gases (CH_3Br + halons; black solid lines). The smooth black solid line prior to 1995 is based on a combination of Antarctic firn air reconstructions and ambient air measurements from a number of studies, adjusted to represent mean global abundances, and updated here with mean ambient air measurements (non smoothed black solid line post-1995) from NOAA global monitoring stations (adapted from Dorf et al., 2006). The dashed line corresponds to the sum of CH_3Br plus halons plus an assumed 6 ppt contribution from VSLS and inorganic tropospheric bromine (from Hendrick et al., 2008).

Terrestrial sources such as rice cultivation, fires and wastewater effluents are also much smaller than the above-mentioned marine sources. Finally, volcanic eruptions may also contribute to the stratospheric halogen burden, but due to their event-like nature their contribution is presumably small, and remains to be quantified.

Much less is known about how and to what degree halogenated VSLS and their PGs are transported from the various sources located at the ground into the LS. Given their short lifetimes, rapid transport of VSLS into the stratosphere requires efficient vertical transport from the troposphere *via* the TTL into the tropical LS (*e.g.* Fueglistaler *et al.*, 2009). Detailed air mass trajectory calculations suggest that major transport pathways for surface air reaching the LS begin mostly from in tropical Western Pacific, and to a lesser degree in the Indian Ocean, tropical Africa and South America during the convective season. However, little is known from direct observations about what fraction of the individual VSLS may survive such a journey, and about the fate of their halogenated PGs and the halogens tied to aerosols. For the PGs, photochemical considerations suggest that they eventually transform into their corresponding hypohalogenated acids (XOH) or halogen acids (HX), which are readily taken-up by aerosols and cloud droplets, and are finally removed from the atmosphere. Furthermore, surface measurements of VSLS undertaken in a critical region (*e.g.* Western Pacific) suggest that only a small fraction (~1%) of the released VSLS, PGs and halogenated aerosols need to survive atmospheric transport in order to explain the observed VSLS contribution to the stratospheric halogen burden (WMO, 2007).

Other aspects of this issue address questions related to the VSLS source strengths, their atmospheric transport and transformation in a changing climate, and consequences for the future stratospheric ozone layer. Current arguments point towards problems such as whether in a predicted warmer climate (1) larger sea surface temperature, and thus potentially more biologically productive oceanic water may lead to larger VSLS emission strengths in sensitive regions, (2) elevated surface temperatures will intensify the vertical atmospheric transport, and (3) a stronger Brewer-Dobson circulation driven by intensified planetary wave activity at mid-latitudes may lead to an increased influx of halogenated VSLS and PGs into the tropical stratosphere with the consequence of enhancing halogen mediated ozone loss there.

In order to address these issues, the European Union (EU) is funding the SHIVA project from July 2009 to June 2012. SHIVA consists of 12 partners from Belgium, France, Germany, Norway and the UK, together with a number of external collaborators. The EU support is 3.5 MEuro, with a similar amount from national agencies. In this article we describe the objectives and the implementation of the project.

Objectives of the SHIVA project

SHIVA aims at reducing uncertainties in estimates of the present and future stratospheric halogen loading and ozone depletion resulting from climate feedbacks between emissions and transport of ozone depleting substances (ODS). Of particular relevance are studies of short and very short-lived substances with climate-sensitive natural emissions. The four major research objectives:

1. The **oceanic emission strengths** of a suite of halogenated source gases will be investigated within a framework of dedicated field studies. These studies will be undertaken in currently understudied, but critical regions of the tropics using ship, aircraft and ground-based instrumentation. Here, emphasis is put on the production, emission and transport of ODS. Inter-dependencies derived from our own field observations, as well as surveys of ongoing work in this area will help establish potential climate sensitivities of VSLS emissions.
2. The **atmospheric transport** and **chemical transformation** of halogenated VSLS and their PGs will be investigated during their journey from the surface to the TTL and finally into the stratosphere using a combination of aircraft and balloon observations, together with process-oriented mesoscale modelling. These investigations will be corroborated by space-based remote sensing of marine phytoplankton biomass as a possible proxy for the ocean-atmosphere flux of VSLS.

3. The **past, present and likely future trend** of the total halogen burden in the stratosphere will be established from the systematic VSLS emission inventory established under Themes 1 and 2. Here, the impact of climate-sensitive feedbacks between transport and the delivery of ODS to the stratosphere, and their lifetime within it, will be studied using tracer observations and modelling. When all this knowledge is combined, the assessed climate sensitivities will eventually support the construction of future-climate scenarios of VSLS emissions and possible pathways for their delivery to the stratosphere.
4. The **impact** of long and short-lived **halogenated SGs** and their **inorganic PGs on past, present and future ozone** will be assessed for the upper troposphere, TTL and global stratosphere. Here, global modelling will include the contribution of all ODS, including VSLS (which have hitherto normally been excluded from such models) to past, present and future ozone loss. The sensitivity of natural ODS emissions to climate change parameters investigated under Theme 3 will be used in combination with standard IPCC climate model scenarios in order to drive measurement-calibrated chemical transport model (CTM) simulations for present and future stratospheric ozone, and to better predict the rate, timing and climate-sensitivity of ozone-layer recovery.

Implementation of the Science plan

The implementation of the science plan was discussed at the SHIVA kick-off meeting, held in Heidelberg, Germany on July 6 and 7, 2009. Meeting minutes and other information on the project can be downloaded from the project web site **http://shiva.iup.uni-heidelberg.de/links.html**. In order to facilitate the management of the project, the SHIVA consortium decided to group the working programme into 6 working packages (WP), each lead by a work package leader. Whilst WP1 is devoted to the management of the project, the other five WPs are directly related to scientific tasks for which the following detailed arrangements were made during the kick-off meeting:

The **atmospheric observations** (WP2) will comprise of ground-based, ship, aircraft, balloon and satellite measurements that aim at the characterisation and monitoring of the atmospheric distribution, oceanic emission strengths of a suite of halogenated gases, their atmospheric transport and transformation and the delivery of these gases into the TTL and LS (**Figure 3**, colour plate IV). The primary region of focus for these measurements programmes will be the Western Pacific, as this is an important region for convective transport of the TTL, and VSLS emission fluxes are likely to be high.

Accordingly, in fall 2009, a first intensive field observation campaign, mostly funded from national resources, will take place in the Western Pacific with a cruise of the German research vessel *Sonne*, from Kushiroshi, Japan to Townsville, Australia. On this cruise, emission fluxes of a suite of VSLS will be measured, together with a detailed analysis of the phytoplankton communities encountered.

As part of a British-Malaysian collaboration associated with SHIVA, the University of Cambridge (UK) and the University of Malaysia (Kuala Lumpur, Malaysia) have installed a μ-Dirac gas chromatograph (GC-ECD) (Gostlow *et al*., 2009) at Tawau, Borneo in Fall 2008, which has since monitored some important halogenated VSLS (*e.g*. CHBr3, CH2Br2). Preliminary data indicate prominent VSLS spikes, which occur during onshore wind bursts, on top of a weak seasonality seen in the measured VSLS concentrations. Five more μ-Dirac instruments are presently being being built for deployment around the Western Pacific in order to obtain a more comprehensive picture on the VSLS distribution in the region. These measurements will be complemented by regular air sample collection at selected locations during SHIVA and analysis for a wider range of VSLS by GC-MS.

The oceanic and surface measurements in the Western Pacific will be compared and contrasted with data collected from other tropical locations, including the Cape Verde Islands in the Eastern Atlantic, where regular halocarbon measurements are made within the international programme SOLAS and the EU funded project TENATSO. Within SHIVA, these measurements at Cape Verde will be supplemented by whole air samples collected on a more campaign based frequency, including during occasional surveys using local ships, and during dedicated deployments of the German research vessels *Poeidon* (October 2011) and *Meteor* (Summer 2001). During these cruises marine waters will be sampled and sea-air fluxes determined for VSLS in the equatorial Atlantic, including the Mauritanian upwelling regions. These oceanic studies will include investigations of the source strengths of the targeted substances with respect to their seasonality, dependence on climate-sensitive factors (such as sea surface temperatures, nutrient supply and biological activity) and dependence on meteorological parameters in the near surface air (*e.g*. temperature and wind speed).

In early 2011, major field activities will take place when the new German research aircraft HALO is deployed into Western Pacific (**Figure 3**, colour plate IV). The HALO aircraft will house 11 instruments, which will provide air-borne observations of transport tracers, a suite of ODS including all major VSLS, relevant atmospheric radicals of the NOx and HOx families, and the most important halogenated PGs (*e.g*. BrO, IO, OIO). Sea-air fluxes of VSLS will also be determined during concurrent cruises of either local ships or from research vessels. Several options currently exist for which ships might be used for the oceanic observations, but a final decision was still pending at the time when this article was written. The aircraft sorties will aim to (1) monitor larger areas for VSLS emission hot-spots, (2) chase VSLS loaded air masses formerly probed by the research vessels, and (3) study the fate of VSLS and PGs in the upper tropical troposphere and lower TTL. The planning and interpretation of the aircraft missions will be supported by detailed meteorological analysis, air mass trajectory calculations and process oriented modelling (see below).

The data gained during these field studies will further be corroborated by ground-based, aircraft and balloon and satellite observations, which will be undertaken by the partners within separate, nationally-funded projects.

The **process studies** (WP3) of atmospheric transport and transformation of halogenated SGs and degradation products investigated during the systematic field studies will also serve as input to process-oriented modelling studies. These process studies will address three major areas:

(1) Pre- and post mission FLEXPART modelling will provide details on the flow patterns of air masses investigated by the

ship and the aircraft. Backward modelling will be further used to gain information on prominent VSLS emission regions of which the exhaust will be probed by the aircraft.

(2) The mesoscale Cat-BRAMS model will be combined with a detailed photochemical scheme for VSLS degradation, degradation product formation and the microphysical removal of halogens in order to provide information on mesoscale convection, and VSLS transport and transformation.

(3) Air mass trajectory modelling driven by actual meteorological fields and diabatic radiative heating rates will allow for assessment of the efficiency of upper tropospheric and cross TTL transport, as function of actual atmospheric parameters, location and season.

An **ocean–lower atmosphere database** (HalOcAt) (WP4) will be established on all available halogenated VSLS and MSLS measurements including those obtained from the SHIVA consortium, *via* informal communication with collaborators, and from the literature. The data will be used for the development of interpretable air–sea gas flux products, for the modelling components of SHIVA, and for the investigation of parameterisations and sensitivity studies in order to predict possible climate feedbacks on oceanic emissions of the targeted gases (*e.g.* changes in SST or wind speeds).

The **past, present and likely future** trend (WP5) of the total halogen burden, and measures of it such as effective equivalent chlorine (EECl) and effective equivalent stratospheric chlorine (EESC), will be established for the global stratosphere. Analysis of past and present trends of the targeted halogens (chlorine, bromine and iodine) will be continued using available and future data from the respective measurements taken by the project partners. Future trends of stratospheric halogens will be established by including surface data of the longer-lived halogenated species (LLS) and their atmospheric lifetimes, as well as the likely contribution of VSLS and MSLS to the individual halogen burdens.

The **impact** of long and short-lived **halogenated trace gases** and **their inorganic product gases** (WP6) will be investigated for past, present and future ozone within the upper troposphere, TTL and global stratosphere. These studies will include global chemical transport model (CTM) simulations driven with past and present decadal-long assimilated meteorological fields, and with general circulation models (GCMs) for the future climate from the Intergovernmental Panel of Climate Change (IPCC) standard simulations.

The possible outcome of SHIVA will therefore be to offer a new perspective on stratospheric ozone-climate interactions from a feedback initiated by future global warming that will possibly lead to (i) increased oceanic productivity and thus VSLS emissions, (ii) a more efficient vertical transport, (iii) an elevated injection of halogenated compounds into the stratosphere, and (iv) an accompanied loss in stratospheric ozone with implications not only for global climate, but also for life on Earth.

The SHIVA consortium welcomes any collaboration with external partners on an equal share of data and results basis, upon signing the SHIVA data protocol, which is available on the SHIVA web site **http://shiva.iup.uni-heidelberg.de/links.html**. In fact to date, collaborations with 6 national and international projects have already been established.

Results from SHIVA will also feed into assessment reports of international research programs and organisations (WCRP, IGBP, WMO, IPCC), and in that respect SHIVA may serve us well in helping to protect our natural environment in the coming, climate-change-affected, decades.

Acknowledgements

Because of its worldwide dimension and its importance for the protection and prediction of the global ozone layer, the SHIVA project will receive funding within the Framework 7 Programme of the European Commission (SHIVA-226224-FP7-ENV-2008-1) from 2009 to 2012. To date, SHIVA has already helped attract additional funding for a larger number of associated national projects. These projects are likely to add to and complement the intended research within SHIVA. Thus, our thanks are extended to all supporting agencies, in addition to those explicitly mentioned here.

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Future SPARC and SPARC-related Meetings

19-23 April	**The CLIVAR International Climate of the Twentieth Century Project (C20C) 5th Workshop,** Beijing, China, http://www.iges.org/c20c/index.html
2-7 May	**European Geosciences Union General Assembly 2010,** Vienna, Austria http://meetings.copernicus.org/egu2010/
10-13 May	**"Earth System Science: Climate, Global Change and People" The AIMES Open Science Conference on Earth System Science,** Edinburgh, UK, http://www.aimes.ucar.edu/
31 May - 4 June	**44th Annual CMOS,** Ottawa, Canada - Special SPARC Session http://www.cmos.ca/congress2010/indexe.html
8-12 June	**International Polar Year - Oslo Science Conference: Polar Science - Global Impact,** Oslo, Norway, http://www.ipy-osc.no/
21 - 23 June	**SPARC DA Worskhop,** Exeter, UK http://www.metoffice.gov.uk/conference/sparc2010/
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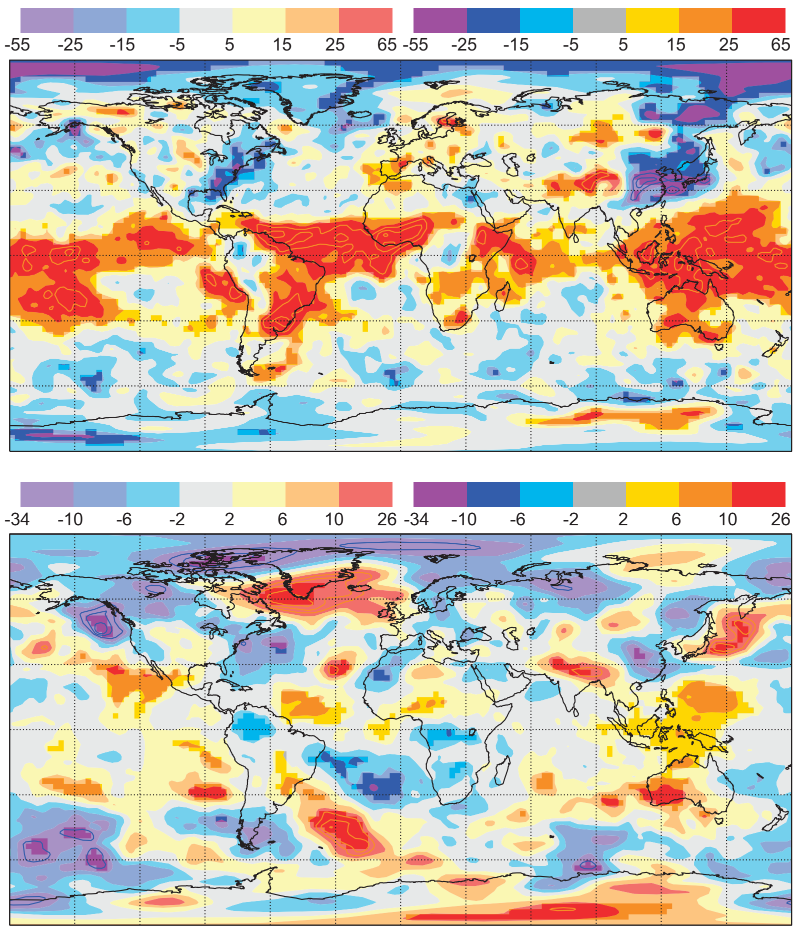
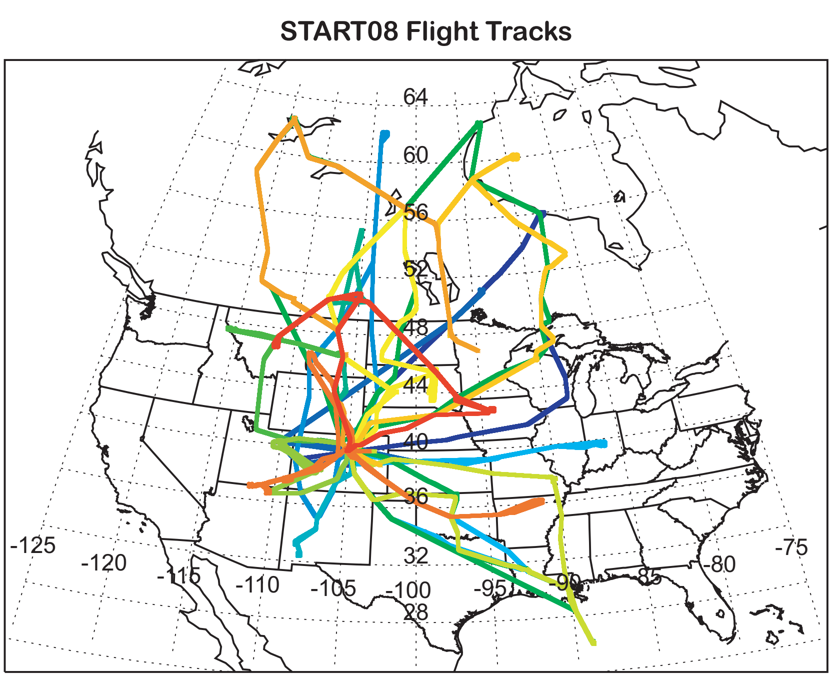


< Figure 1

Mean forecast error of temperature at 500 hPa based on ECMWF daily forecasts initiated at 0UTC during the period December 2007 - February 2008. The upper panel shows mean forecast error at a lead-time of 1 day with a shading/contour interval of 0.1 K. The lower panel shows mean forecast error at a lead-time of 10 days with a shading/contour interval of 0.4K. Statistical significance at the 5% level (using a Student's t-test and taking autocorrelation into account) is indicated by the bold colours.

The Stratosphere-Troposphere Analyses of Regional Transport 2008 (START08) Experiment

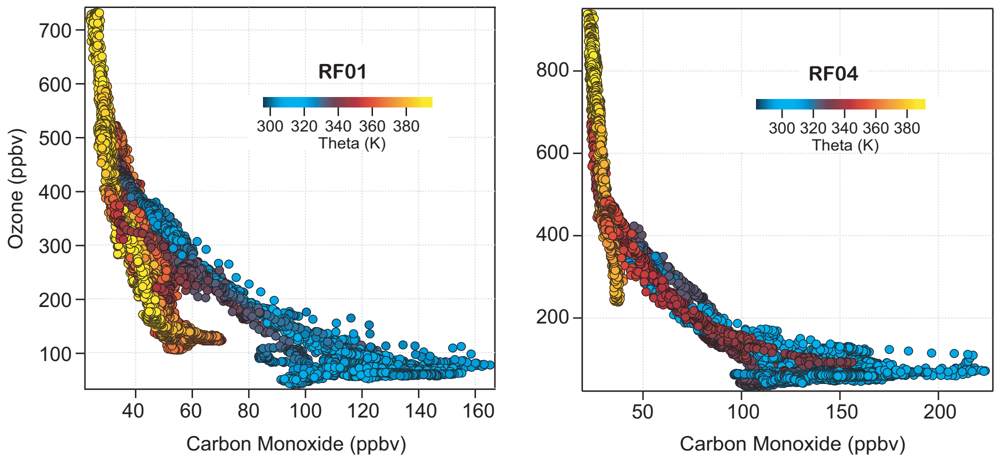


< Figure 1

Flight tracks of the START08 mission, which covered much of central North America from near surface to 14 km.

I

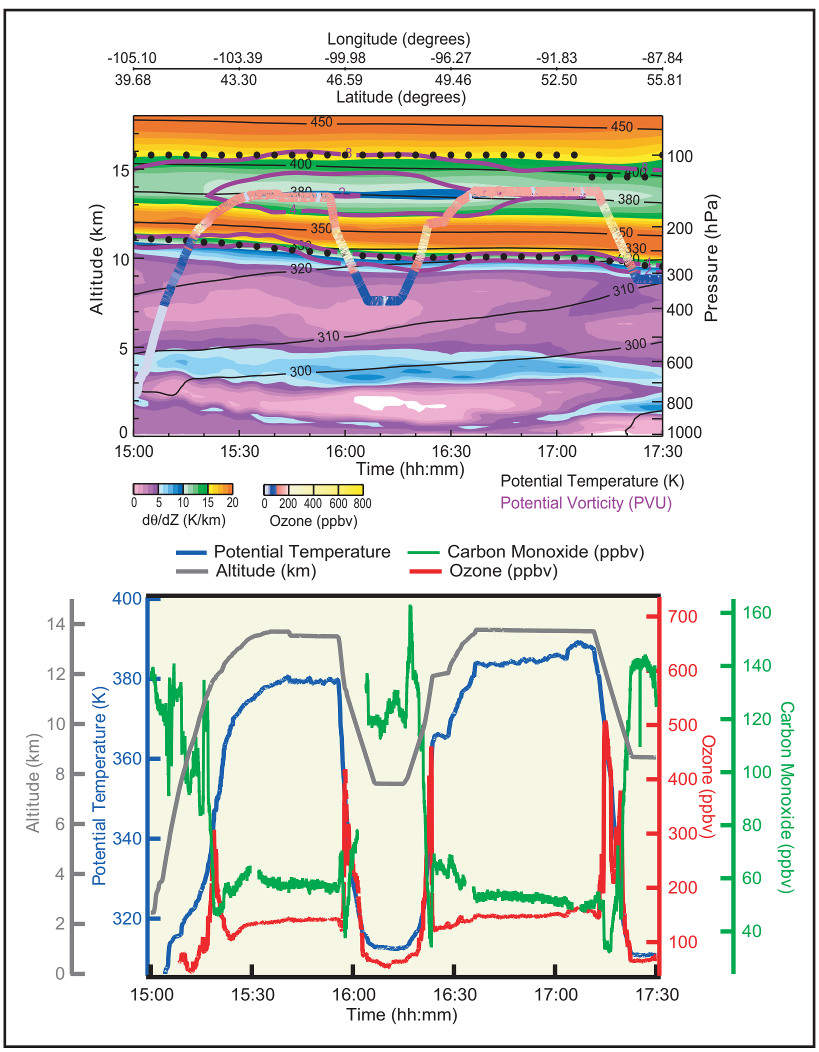
The Stratosphere-Troposphere Analyses of Regional Transport 2008 (START08) Experiment



^ Figure 3

O3:CO correlations for START08 flights RF01 (tropospheric intrusion flight) and RF04 (stratospheric intrusion flight). The yellow-orange shading represents high values of potential temperature associated with the intrusion of tropospheric air into the LS. Blue shaded points indicate mixing with the troposphere along lower theta surfaces associated with the jet stream.

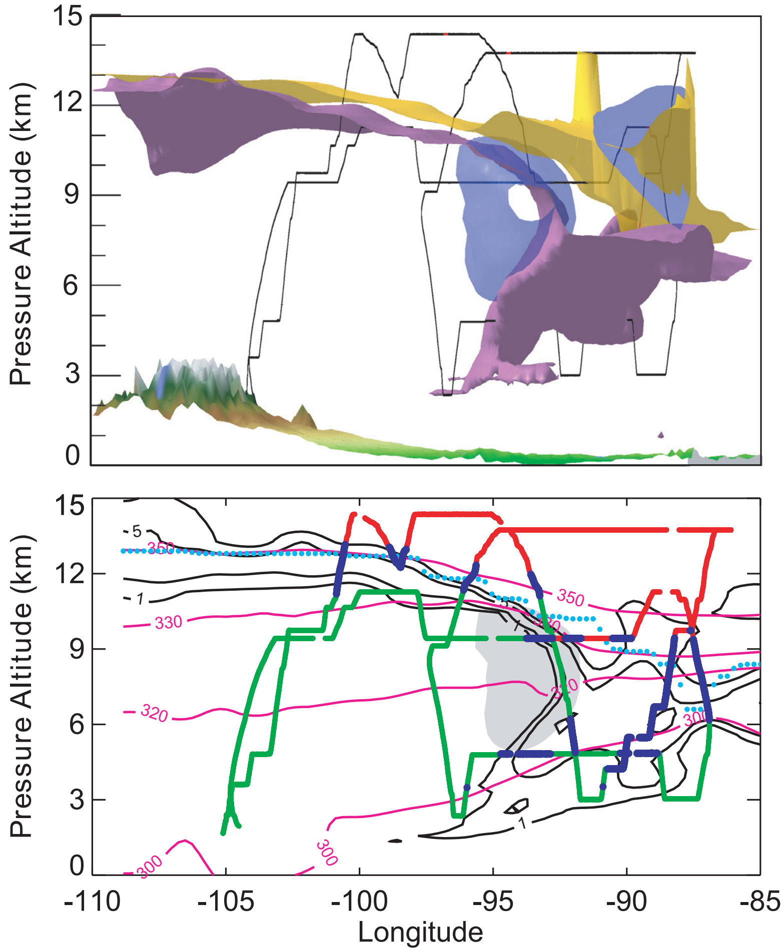
II



< Figure 4

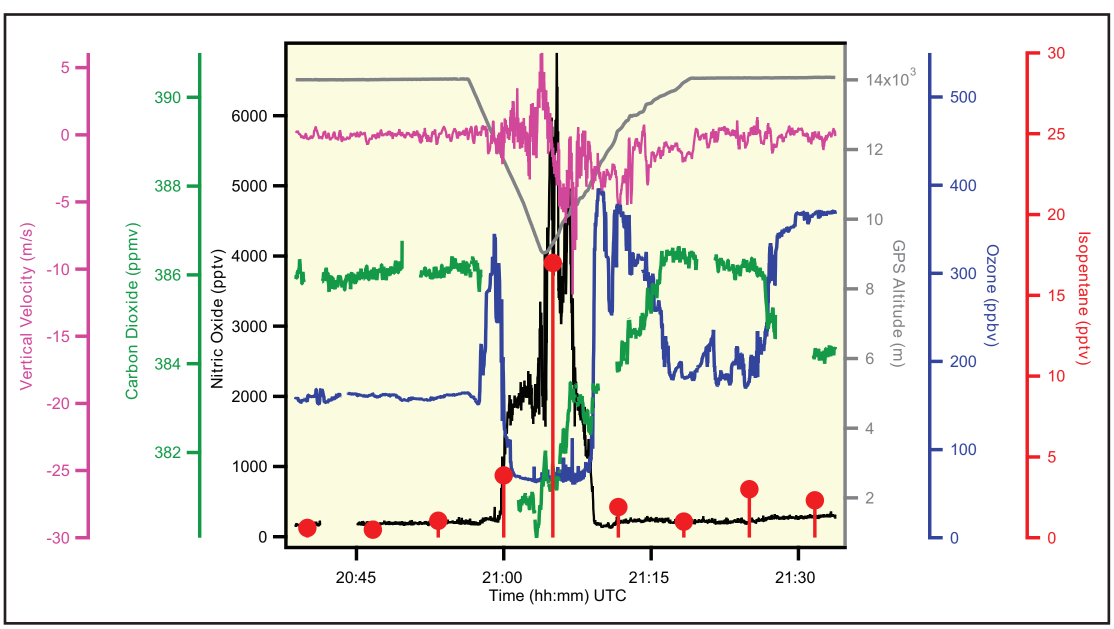
(Upper panel) Cross-section of atmospheric stability (dq/dz) overlaid with the aircraft flight profile for RF01. The low stability air is associated with a tropospheric intrusion. (Lower panel) Time series of ozone and carbon monoxide as the aircraft passed into and out of the tropospheric intrusion layer. The high stability layer just above the tropopause is characterised by typically stratospheric levels of high ozone and low carbon monoxide.

The Stratosphere-Troposphere Analyses of Regional Transport 2008 (START08) Experiment



< Figure 5

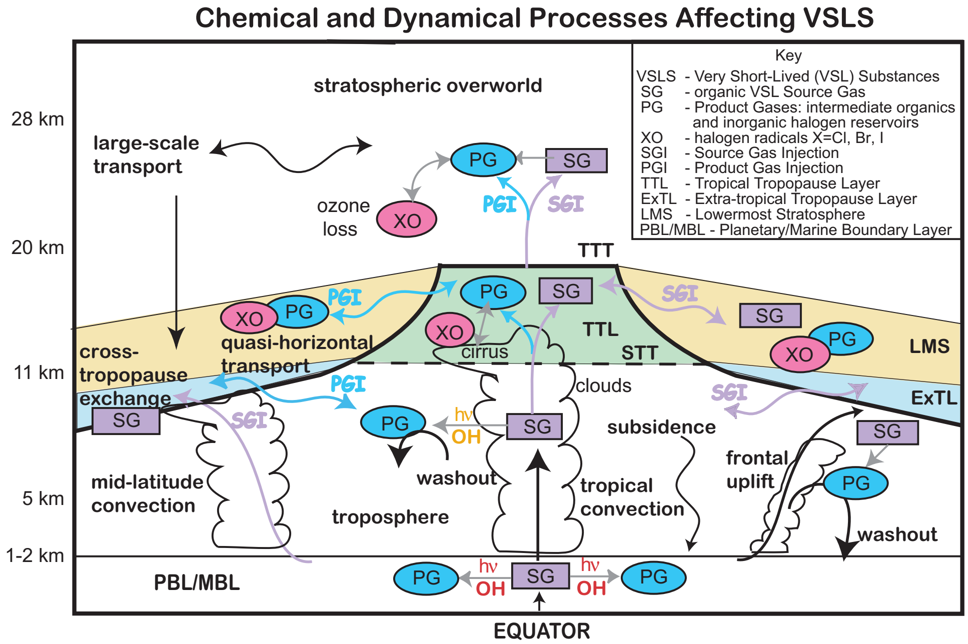
(Upper panel) The purple surface represents 2 PVU surface. Yellow is the thermal tropopause. Blue indicates the position of the subtropical jet. The solid black line represents the GV flight track. (Lower panel). Vertical sections of theta (pink), PV (black), and thermal tropopause (dotted cyan). The flight profile is coloured by tropospheric data (green), stratospheric data (red), and regions of mixing (blue).



^ Figure 6

Time series of trace gas measurements and aircraft vertical velocity and altitude during a descent into a convective system over Southern Manitoba.

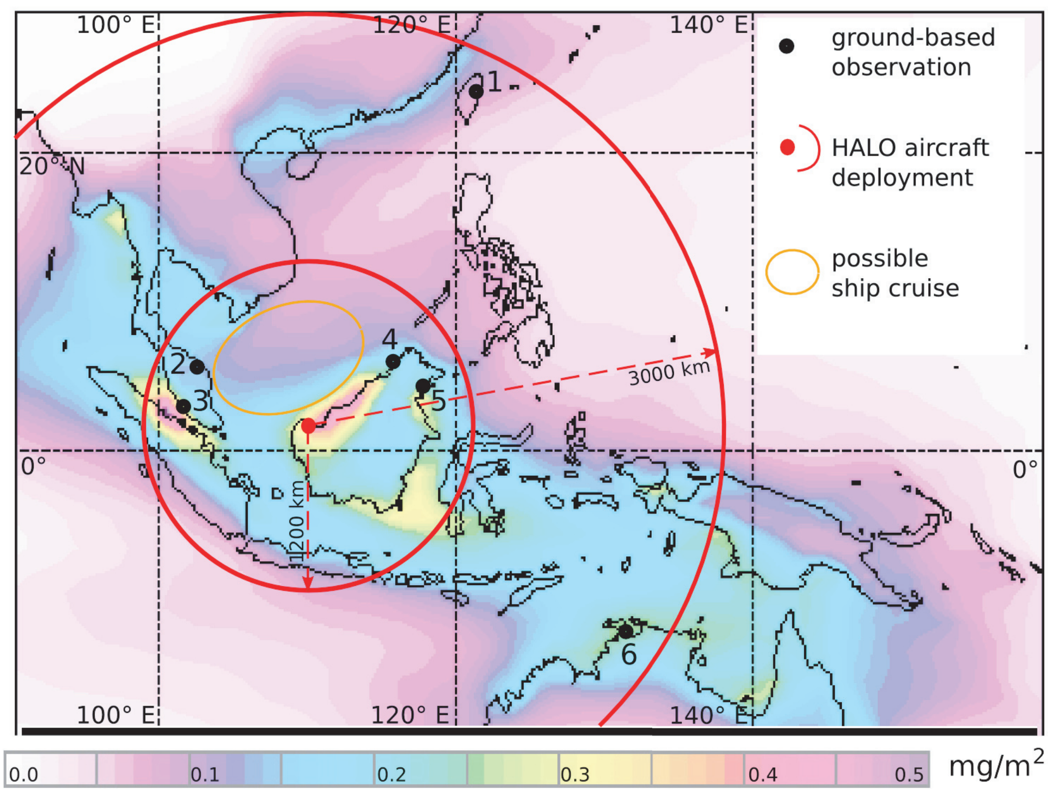
The EU project SHIVA (Stratospheric ozone: Halogen Impacts in a Varying Atmosphere)



< Figure 2

Schematic showing principal chemical and dynamical pathways transporting VSL source gases (SG) and organic/inorganic product gases (PG). Stratospheric halogen loading is maintained by transport of source gases followed by their degradation in the stratosphere (the SGI pathway), and transport of intermediate products and inorganic halogens produced in the troposphere (the PGI pathway). Tropospheric inorganic halogens can derive from degradation of VSL SGs, or from inorganic halogen sources (adopted from WMO, Figure 2.1).

IV



^ Figure 3

Overview of the SHIVA field activities in the Western Pacific in 2011. The coloured plot in the background shows modelled column concentrations of $CHBr_3$ in mg/m^2 from FLEXPART simulations for a tracer with a 5-day lifetime and estimated $CHBr_3$ emissions based on GLOBCOLOUR chlorophyll concentration from Feb. 1-28, 2009 (courtesy T. Dinter and B. Quack). The black dots (1 to 6) mark planned ground-based observations by the Cambridge μ-Dirac instruments. The red circles indicate the maximum range of the HALO aircraft for 8h (radius 1200 km) and 1h (radius 3000 km) loitering time in the targeted region for a deployment of the HALO aircraft at Kuching/Borneo (1° 30'N, 110° 20'E). The yellow ellipse illustrates the area of possible cruises by local or larger research ships.