



View from the cockpit of the new High Altitude and LOng Range (HALO) research aircraft during a measurement flight on 11 September 2012 as part of the Earth System Model Validation (ESMVal) campaign from Cape Verde to Cape Town. Chemical data were sampled for the evaluation of chemistry-climate models. A line of tropical thunderclouds off the coast of west Africa is visible. The IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) is planning to use these and other aircraft measurements for model evaluation, and overall the activity aims to improve the comparability between models and measurements (Photo: Hans Schlager).

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Report on the 34th Session of the Joint Scientific Committee of the World Climate Research Programme 27-31 May 2013, Brasilia, Brazil

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Tony Busalacchi, chairperson of the Joint Scientific Committee (JSC, which oversees the work of WCRP), opened the meeting by welcoming all participants.

Carlos Nobre (former JSC member) welcomed all participants on behalf of the Brazilian Ministry of Science, Technology, and Innovation, local organisers of the meeting. He highlighted developments made in Brazil toward furthering climate-related research and policy.

Tony Busalacchi set the stage for the JSC meeting, providing a general overview of the current status of WCRP. He emphasized the need for flexibility and the ability to respond to expanding user needs, particularly at the regional scale, for key sectors of the global economy, as well as for adaptation, mitigation, and climate-related risk management. He recalled the evolution of WCRP's structure to reflect societal requirements, including the Grand Challenges (see www.wcrp-climate.org/index.php/grand-challenges). He also discussed the progress since JSC-33 (see SPARC Newsletter 40, www.sparc-climate.org/fileadmin/customer/6_Publications/Newsletter_PDF/40_SPARCnewsletter_Jan2013_web.pdf), clarified the priorities of the meeting, and mentioned the new Future Earth initiative

(see www.futureearth.info). Future Earth will expand beyond the existing global networks, for example by including new institutions and stakeholders, as well as by promoting dialogue with politicians. WCRP will be associated with Future Earth, providing the scientific basis of the physical climate system for Future Earth projects.

Tony Busalacchi reminded the session that a 'membership committee', consisting of JSC members chaired by the JSC vice-chair, was established at the 33rd JSC session. This committee is to work with WCRP bodies to fill vacant positions, taking into consideration gender, regional representation, and age distributions. This process needs to be completed in a timely manner and that all pertinent information is provided to ensure a well-informed decision can be made by the JSC. He continued by highlighting the importance of communication across the WCRP and mentioned the newly prepared Accomplishment Report. He also warmly thanked three outstanding scientists, Martin Visbeck, Gerald Meehl, and Kevin Trenberth, for their important contributions to WCRP and climate science. They stepped down at the end of 2013.

Dialogue with Sponsors and Stakeholders

Jerry Lengoasa, Deputy Secretary-General of the WMO (World Meteorological Organisation), reaffirmed WMO's sponsorship of WCRP and indicated that the WMO Executive Council (EC) reviewed WCRP at its 65th session (EC-65) and has endorsed several WCRP initiatives. WMO is an observer in the Science and Technology Alliance for Global Sustainability, which leads the Future Earth initiative. At the WMO EC-65 it was pointed out that the close collaboration between the GFCS (Global Framework for Climate Services) and Future Earth would be mutually beneficial to ICSU (International Council for Science) and WMO. Jerry Lengoasa also briefly reviewed the status and development of the GFCS, whose main aim is to better manage the various risks of climate variability and change, including adaptation to climate change through the incorporation of science-based climate information and prediction into planning, policy, and practical applications at global, regional, and national scales. The framework intends to fill the gap between those that need this knowledge and those that have this knowledge, with 'actionable' science being a clear priority. Within WCRP, the Working Group on Regional Climate (WGRC) provides the interface

between researchers and the GFCS delivery of services. Jerry Lengoasa emphasized the crucial importance of WCRP's commitment to lead the GFCS implementation related to research, modelling, prediction, and research-based observations. This will naturally involve working with National Meteorological and Hydrometeorological Services and academia/university science.

Returning to the Future Earth initiative, **Steven Wilson** presented the main concept of Future Earth and discussed the current status of planning and related changes in the GEC programmes. Future Earth will merge the DIVERSITAS, IGBP, and IHDP programmes from the middle of 2014. Future Earth aims to provide the knowledge necessary for societies to face the risks related to global change and to manage the transition to global sustainability. The initiative has three main research themes, namely the 'Dynamic Planet', 'Global Sustainability', and 'Transformation towards Sustainability'. Activities, carried out largely through partnerships, will cover the following topics: observing systems, data systems, Earth system modelling, theory development, synthesis and assessments, capacity development and education, communication, as well as the science-policy interface and interactions. In the discussion, it was mentioned that many existing collaborations between the IGBP and WCRP need to continue.

Frederico Nogueira started his presentation on the IOC (International Oceanographic Commission) by listing its 'high-level objectives' which include: (1) preventing and reducing impacts of natural marine hazards, (2) mitigating impacts and adapting to climate change, (3) safeguarding the health of ocean ecosystems,

and (4) promoting policies for sustainability. WCRP plays a key role in the second of these objectives, providing a link with the UNFCCC (United Nations Framework Convention on Climate Change) and the IPCC (Intergovernmental Panel on Climate Change). WCRP, together with GOOS (Global Ocean Observing System) and GCOS (Global Climate Observing System), is one of the co-sponsors for the Ocean Observing System Panel for Climate and is engaged in research providing the scientific basis for GOOS. The IOC is implementing a Framework for Ocean Observing, within which a key idea is the definition of 'Essential Ocean Variables', which have some overlap with 'Essential Climate Variables' (ECVs). The renewed CLIVAR (Climate Variability and Predictability, see below) priorities closely match the climate goals of IOC, and thus closer collaboration with IOC regional structures could serve the development of observing systems, research, and services related to IOC and CLIVAR.

Joint Planning Staff (JPS)

Ghassem Asrar, the then director of the WCRP Joint Planning Staff (JPS, which provides crucial support to all WCRP activities), reported on the status and activities of the JPS. The WCRP budget is presently stable because of contributions from sponsors and national contributions under ICSU, despite the reduction of the IOC's contribution following financial limitations of UNESCO (United Nations Educational, Scientific and Cultural Organisation). He also presented several highlights of events organised and supported by WCRP. He concluded by stating that WCRP support for high priority climate science activities continues to grow and that the focus on regional climate science and

the WCRP's Grand Challenges was gaining momentum.

Later during the meeting Ghassem Asrar gave a presentation about WCRP communication and capacity development on behalf of Roberta Boscolo, the WCRP communications officer. The WCRP communications, outreach, and capacity development strategy is ambitious, aiming to produce reliable, science-based climate information; attract the best minds from the scientific community to continue providing a global context and integrative framework for regional climate research; increase public awareness about the importance of climate for sustainable development; enhance the visibility of WCRP activities and products; support information exchange between the WCRP secretariat and the projects; and, assist WCRP in securing the necessary resources to fulfil its objectives. The WCRP communications team conducts monthly virtual meetings to improve outreach development and to share ideas to promote communication between the projects. They also issue the WCRP Community News, a collection of news items from CLIVAR, CliC, GEWEX, SPARC, and CORDEX (for abbreviations see below), which automatically feed on to the WCRP's Facebook and Twitter pages. An important achievement is the WCRP community calendar, which displays information from the four core projects and related programmes, and which is found on the new WCRP website which was launched in March 2013.

Ghassem Asrar continued by providing a short overview of the goals and achievements of WCRP capacity development and outreach. The main focus is on building research capacity in developing regions and

empowering the next generation of climate scientists. A large number of WCRP-sponsored conferences and summer schools, as well as CORDEX workshops, have been organised. They have, and will, provide many opportunities for promoting scientific exchange and strengthening connections between research communities. Building a WCRP-wide network of early career scientists will involve creating networks for each core project (if they do not already exist), efficient use of social media to enhance interactions, facilitating participation in international research, and providing opportunities to learn additional skills.

Agency Updates

Richard Rosen started his presentation on NOAA (National Oceanic and Atmospheric Administration) activities by noting the increasing demand for climate science and services. In response, NOAA's strategic plan includes the following 'Climate Goal Objectives': improved scientific understanding of climate change and related impacts; assessments of current and future states of the climate system useful for science, service, and stewardship decisions; mitigation and adaptation efforts supported by sustained, reliable, and timely climate services; and, a climate literate public that understands its vulnerability to climate change and can make informed decisions. All five NOAA line offices will contribute to climate research focused on the sustainability of marine ecosystems, coasts and climate resilience, impacts on water resources, weather/climate extremes, as well as on the development of corresponding climate services.

Joerg Schulz presented an update from CEOS (Committee on Earth Observation Satellites), CGMS

(Coordination Group for Meteorological Satellites), and EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites). The CEOS Working Group on Climate's (WG-climate) mission consists of facilitating the implementation and exploitation of ECVs through the improved coordination of climate monitoring activities of the major space agencies. The group is to develop metrics, ECV inventories, and assessments to further the development of climate monitoring from space (as described in the Strategy Report on Climate Monitoring Architecture). WG-climate and CGMS initiated a web-based questionnaire on ECVs, relating to usage, properties, and access issues (e.g. format). The questionnaire comprises two parts focused on existing and planned missions and will remain open for continuous submission and analysis. The inventory of responses to the ECV questionnaire can be used for several purposes, for example, to cluster climate observation applications with respect to GFCS priorities and WCRP Grand Challenges. WG-climate activities will also contribute to climate data stewardship. This work could also potentially be extended to cover *in situ* data as well. The 5-year CGMS high-level priority plan, which was recently endorsed, reflects a longer-term perspective on the new challenges for climate monitoring in the context of the GFCS. One of the main priorities of this plan is to extend the Global Space-based Inter-Calibration System and the Sustained, Coordinated Processing of Environmental Satellite Data for Climate Monitoring.

Joerg Schulz then continued with an update of EUMETSAT activities. In November 2013 the EUMETSAT council endorsed its Climate Monitoring Implementation Plan, which includes the EUMETSAT Data Set

Generation Plan. This plan supports the generation of data records contributing to 17 ECVs (10 atmospheric, 2 oceanic, and 5 terrestrial) and the European Reanalysis of Global Climate Observations. In partnership with GCOS, CEOS, and the CGMS, WCRP and EUMETSAT are organising a conference on 'Climate Research from Space: Climate Information for Decision Making', to be held in Darmstadt, Germany, from 13-17 October 2014. One of the main aims of the conference will be to identify gaps in the current space-based climate observing system and to discuss a post-IPCC AR5 joint action plan for developing observing systems, particularly focused on the space component.

Adrian Simmons presented an overview of developments at the ECMWF (European Centre for Medium-Range Weather Forecast). One of the continuing foci of ECMWF is a more seamless approach to global prediction. To this end, they are supporting the WMO WWRP (World Weather Research Programme) proposal to initiate a new programme, 'Predicting Weather and Climate Extremes', which would cover prediction timescales of up to one year. The link between WWRP and WCRP will be vital for this programme, the success of which would provide a key opportunity to model events that need to be represented in both weather forecast and climate models. The ECMWF medium- and monthly-range prediction systems are moving towards the use of a coupled ocean model from day 0 (rather than day 10) and the development of resolution and mixed-layer representation in the model. The seasonal-range prediction system is being developed by combining products with the monthly-range forecasts. The capability of the

two systems to forecast droughts and for use in disease prevention is being tested. The seasonal-range system will include a sea-ice model and further developments of snow-cover, vegetation, volcanic aerosol, and stratospheric representations are to be carried out (mainly through external project funding). The development of data assimilation will include a move to longer time windows and a more dynamic representation of the background and analysis uncertainty.

ECMWF is actively engaged in the development of the EU project “Copernicus” (previously GMES: Global and regional Earth-system (Atmosphere) Monitoring using Satellite and *in situ* data), as well as several reanalysis projects, an important component of climate services. The current ERA (ECMWF Reanalysis)-CLIM project (2011–2013) is devoted to producing a global atmospheric reanalysis of the 20th century. The follow-up project, ERA-CLIM2 (2014-2016), will be aimed at providing a 20th century reanalysis of the ocean and carbon cycle.

WCRP Science Grand Challenges

Regional Climate Information

As part of the discussion of the ‘Regional Climate Information’ Grand Challenge, **Ghassem Asrar** presented material on behalf of the WGRC co-chairs (Clare Goodness and Bruce Hewitson). At its very first meeting held in April 2013, WGRC decided to develop an action plan and produce a guidance document on the use of regional climate information. WGRC will also review regional climate information based on observations, and will consider observational requirements for regional climate services.

Filippo Giorgi presented the WCRP CORDEX (Coordinated Regional Downscaling Experiment) modelling framework, which is designed for the evaluation and improvement of Regional Climate Downscaling (RCD); to provide coordinated sets of RCD-based projections and predictions; as well as to facilitate communication with the impacts, adaptation, and vulnerability community, as well as climate researchers from developing countries. The original Task Force on RCD successfully terminated its work and CORDEX activities are now an important task of WGRC. CORDEX has been successful in promoting and expanding its modelling framework, with a large number of groups participating in producing simulations and with several articles to be published in leading research journals. An important change will take place in terms of CORDEX data management, which will now be made available on the Earth System Grid. CORDEX also organised a large conference, the ‘International Conference on Regional Climate – CORDEX’, which took place from 4-11 November 2013 in Brussels, Belgium.

Celeste Saulo presented the ‘Conference on Climate and Society for Latin America and the Caribbean (LAC): Developing, linking, and applying climate knowledge’, which will take place in Montevideo, Uruguay, from 17-21 March 2014. This conference will also address new priorities for climate research for the region. The five proposed themes are: water and energy, agriculture and ecosystems, human health, coastal zones, urban environments, and the general theme of climate monitoring, prediction, and predictability of the LAC region.

Frederick Semazzi and **Pius Yanda** presented the Africa Climate Con-

ference, which took place in Arusha, Tanzania, from 15-18 October 2013. The main objective of the conference was to draft a climate research agenda for Africa focused on sustainable development and linked to present policy processes, partners, and institutions. Research priorities will be addressed in close collaboration with the information needs of African end-users, policy developers, and vulnerable communities so as to successfully adapt to a changing climate and provide optimal management of the related risks.

Linda Anne Stevenson discussed the Asia-Pacific Network for Global Change Research (APN). APN is both a funding agency with resources from Japan, USA, the Republic of Korea, and New Zealand, and a network of 22 member countries with representatives from policy and science communities. The current strategic goals of APN include: supporting regional cooperation in global change research, strengthening the dialogue between scientists and policy makers, improving scientific and technical capabilities, as well as cooperating with other global change networks and organisations. The APN science agenda focuses on: climate change and variability; ecosystems, biodiversity, and land use; changes in atmospheric, terrestrial, and marine environments; and resource utilisation and pathways to sustainable development. The APN Climate Adaptation Framework supports development of high resolution observational, model, and downscaled data contributing to filling of data gaps; calibration and validation of regional climate models; analysis of projections including assessments of uncertainties; impact, vulnerability, risk, and economic assessments; and science-policy communication. APN is closely following the development of the Future Earth initiative.

Implementation of the 'Regional Climate Information' Grand Challenge

Lisa Goddard (CLIVAR co-chair; CLIVAR is responsible for the implementation of this Grand Challenge) presented thoughts on the implementation of sub-themes of the 'Regional Climate Information' Grand Challenge. One approach would be to use CLIVAR's existing experience and capacity in the areas variability and predictability on intraseasonal through to decadal scales to provide the results necessary to achieve the main objectives of this Grand Challenge. One of her main conclusions was, however, that a global solution suitable for all regions does not exist and as such a regionally specific plan needs to be developed. The implementation of this Grand Challenge might therefore require the formulation of more specific research themes, which would need to be explored in terms of the community's readiness to study these topics, funding opportunities, and the need for WCRP/CLIVAR coordination. Monsoon systems, which strongly influence water availability in many vulnerable developing nations, could be considered as a possible smaller research theme. Key areas for progress on the 5-10 year time-scale could include: improved model constraints on monsoon variability and change, better description of key processes in numerical models, improved monsoon prediction using land surface modelling and based on land surface initialization, and better understanding of possible anthropogenic change on monsoon systems. Decadal prediction experiments from CMIP5 (Coupled Model Intercomparison Project - Phase 5) might be analysed to address these questions, as could investigations of the predictability

related to stratosphere-troposphere coupling, which is currently being developed by SPARC through the DynVar (Dynamical Variability) and SOLARIS/HEPPA (Solar Influence/High Energy Particle Precipitation in the Atmosphere) activities.

More general issues relevant to the Grand Challenge are related to the quality of observations and analyses, data sharing between model and observation communities, and effective communication with the broader research community. Concerning delivery of climate information to policy makers (*e.g.* supporting GFCS), she pointed out that WCRP should focus on improving scientific understanding, maintaining climate-quality observations, developing models that represent relevant climate processes, and making these services and tools easily accessible to the broader scientific community and decision makers.

'Clouds, Circulation, and Climate Sensitivity' Grand Challenge

Sandrine Bony (lead coordinator together with Bjorn Stevens) discussed the implementation of the Grand Challenge on 'Clouds, Circulation, and Climate Sensitivity'. One of the major challenges facing this Grand Challenge is the large spread in modelled climate sensitivities, as evidenced by CMIP5 results. This spread is largely attributable to the treatment of clouds, which not only affects estimates of climate sensitivity, but also contributes to the high uncertainty in regional precipitation projections. A major part of model uncertainty also stems from the difficulty in quantitatively predicting the response of large-scale circulation systems to climate change, especially in the tropics. Although models have become more

and more complex, meaning that more complex problems can now be addressed, this development has not reduced the key uncertainties affecting climate projections. The most important uncertainties are still related to basic physical processes concerning interactions between atmospheric water vapour, temperature, and circulation. The Grand Challenge will be implemented through five major initiatives focused on: (1) climate and hydrological sensitivity: designing critical tests to assess the most reliable estimates of climate and hydrological sensitivity; (2) coupling clouds to circulation: tackling the parameterization problem by improving understanding of the interactions between clouds, convection, and circulation systems; (3) changing patterns: studying the relations between large-scale circulation patterns and anthropogenic forcings from greenhouse gases, aerosols, and ozone; (4) leveraging records of the recent and longer past: studying observations of the recent past and proxies for longer-term changes to better constrain cloud processes and related feedbacks, including improvement of paleo-climate reconstructions; (5) towards more reliable models: analysing and reducing model errors and studying the effect of errors on projections and predictions focusing on long-standing model biases. Overall, the Grand Challenge will be led by the WGCM (Working Group on Coupled Modelling, see below) in close collaboration with GEWEX (Global Energy and Water Exchanges, see below)/GASS (Global Atmospheric System Studies), WGNE (Working Group on Numerical Experimentation, see below), and SPARC. The team is planning to sharpen the individual initiatives by clarifying key science questions, identifying possible on-

going and planned projects that can be leveraged, and motivating the research community to contribute to the initiatives.

‘Cryosphere in a Changing Climate’ Grand Challenge

Vladimir Kattsov presented this Grand Challenge on behalf of Greg Flato (chair of CliC, Climate and Cryosphere; CliC will implement the Grand Challenge). There are many compelling reasons for undertaking this Grand Challenge, including the expectation of an ice-free Arctic ocean, the future of mountain glaciers that supply fresh water to millions of people worldwide, the positive feedback between a warming climate and thawing permafrost, and the role of ice-sheet dynamics amplifying Greenland’s contribution to global sea level rise. These problems are not only important topics within the research community but are highly relevant to society. Furthermore, processes related to the cryosphere remain an important source of uncertainty in projections of future climate change.

The outcomes from this Grand Challenge should result in improved confidence in climate models and their predictions/projections of cryospheric changes, particularly the expected timing of the disappearance of multi-year Arctic sea-ice and the fate of mountain glaciers. A better quantification of the most important cryosphere-climate interactions is expected to improve global and regional climate predictions on monthly to decadal time-scales, as well as long-term projections, particularly with respect to the carbon cycle. The more specific research goals on a 5-10 year horizon can be summarized as:

- Research on seasonal, interannual,

and longer-term predictions/projections of polar climate and the role of the cryosphere in climate predictability.

- Model intercomparisons to specifically understand and attribute model biases as related to the cryosphere.
- Improvement of the representation of permafrost and high-latitude land surfaces (including wetlands) in climate models, particularly related to the carbon cycle.
- Development of ice sheet models particularly addressing ice sheet dynamics and their effect on sea-level rise.

CliC will coordinate research activities among several national and international scientific projects that are active in permafrost and carbon research, and which were developed by CliC under its CAPER (CARbon and PERmafrost) initiative. Coordination of such activities, as well as identification of new activities, is vital to the success of this Grand Challenge. The implementation of the Grand Challenge was discussed at a dedicated workshop ‘Cryosphere in a Changing Climate’, held in October 2013 in Tromsø, Norway.

‘Attribution and prediction of extreme events’ Grand Challenge

Kevin Trenberth (GEWEX co-chair until end 2013; GEWEX is leading the implementation of this Grand Challenge in partnership with CLIVAR) presented the development of this Grand Challenge. The present plans make use of recommendations from a WCRP/UNESCO - GEWEX/CLIVAR/International Hydrological Programme workshop on metrics and methodologies for estimating extreme climate events (rainfall, drought, heat waves, floods, and storms) held in September 2010.

Key research themes of the Grand Challenge are:

- Improving both historical and real-time *in situ* observational data sets for better characterization of extreme weather and climate events and better quantification of the ocean states that influence these extremes.
- Quantifying long-term changes in extremes and understanding their causes, particularly the physical mechanisms and processes underlying these events.
- Studying the processes and physical mechanisms through which modes of variability and atmosphere-ocean interactions and feedbacks can affect the frequency and magnitudes of extremes.
- Extending operational seasonal prediction capabilities.
- Harnessing advances in climate model development and initialization for decadal and long-term predictions to better estimate changes in the frequency of occurrence of extreme events.

‘Change in Water Availability’ Grand Challenge

Kevin Trenberth went on to discuss this Grand Challenge, led by GEWEX. The main goal of this Grand Challenge is to improve scientific understanding and prediction of precipitation variability and change, as well as to interpret the connection between land surface and hydrology, particularly in terms of past and future changes in water availability. To address these challenges, studies in the following areas are required:

- Improving data sets of precipitation, soil moisture, evapotranspiration, and other variables such as water storage and sea surface salinity. More focused evaluation of model pre-

precipitation in the tropics (where errors are largest) using Tropical Rainfall Measuring Mission satellite data, which provide good quality and coverage over this region, could lead to better understanding of causes of biases such as the double ITCZ (Inter-Tropical Convergence Zone), weak tropical transients, and easterly waves.

- Progressing analyses aimed at closing the water budget over land. Improvements can be expected through the exploitation of new data sets, data assimilation, as well as an improved understanding of the physics and hydrological modelling across all scales involved. New and more reliable measurements from remote sensing platforms are expected to narrow the large uncertainties that still exist.
- Improving modelling capabilities at all scales, from global climate models through to regional hydro-climate models. This includes better representation of the effects of land use changes and hydrology on water availability and security, as well as the effect of climate change on terrestrial ecosystems, hydrological processes, water resources, *etc.*
- Providing appropriate information related to water availability and quality, which is required for decision-making and for initializing climate predictions on seasonal and longer time scales.

Based on progress in the items listed above, this Grand Challenge has the potential to improve models so as to better predict precipitation on different temporal and spatial scales, better quantify uncertainties in climate and water cycle products, improve information regarding extremes, and develop a Drought In-

formation System. Such information is expected not only to improve interactions between the research community and users, but also to provide a better scientific basis for water managers, decision makers, and users.

‘Regional sea-level’ Grand Challenge

Martin Visbeck presented the Grand Challenge on regional sea-level (RSL) rise on behalf of CLIVAR, who is leading this Grand Challenge. RSL change is directly relevant for society and is affected both by components of the climate system and several other factors unrelated to climate change. RSL change and variability strongly vary on spatial scales, and available reconstructions suggest non-stationarity of spatial trend patterns, as well as complex links with climate modes such as the El Niño-Southern Oscillation, Pacific Decadal Oscillation, and the North Atlantic Oscillation.

The following processes are known to contribute to RSL change: adiabatic redistribution of upper-layer water, which is strongly affected by wind-driven currents associated with climate modes on interannual to decadal time scales; changes in heat and fresh water uptake, for example, from glaciers and ice sheets (important on longer time scales); ocean dynamics; gravitational effects; abyssal (depths greater than 2000m) warming, with differences between ocean basins; as well as vertical land motion (glacial isostatic adjustment). The following aspects remain particularly challenging: scenario uncertainty (for global mean sea level and RSL rise); inter-model spread, which is largely attributable to strong differences in simulated ocean circulation changes; and

significant internal variability (*e.g.* on decadal time scales), which suggests that predictions of RSL rise on these time scales may be highly dependent on initial conditions.

Interaction between the modelling, glaciological, and geodetic research communities is needed to: (1) reduce uncertainties in climate models regarding sea level rise, (2) introduce missing components and processes into climate models (*e.g.* ice-sheet dynamics and mass loss, or changes in hydrology), and (3) initiate a coordinated modelling effort with improved representation of regional ocean dynamics.

WCRP councils

John Mitchell and **Christian Jacob** discussed the WMAC (WCRP Modelling Advisory Council). It was agreed that the achievement of many Grand Challenge goals would require major model improvements and that additional tasks associated with the Grand Challenges may stretch the modelling community even further. Thus, better coordination of modelling activities is needed. WMAC also had reservations regarding CMIP6, preparations for which have already started. There is a need for a strategy to significantly improve models, which requires both significant expertise and time. It was suggested that prizes for important contributions to model development be established, potentially with a focus on early career scientists. WMAC has formed a small task team to implement this. Finally, WMAC also proposed two workshops, one focused on model ‘tuning’ and another on the coupling of model dynamics and physics.

Otis Brown presented WDAC (WCRP Data Advisory Council) activities. WDAC works together

with WMAC to promote the use of observations for model validation and to address questions regarding data assimilation, reanalyses, observing system experiments, fluxes, and paleoclimatic data. WDAC keeps the development of SCOPE-CM under review and encourages the use of the GOSIC-CEOS-CGMS (GOSIC: Global Observing Systems Information Center) tool for ECV inventories. WDAC established a task team to advise on OBS4MIPS (Observations for Model Intercomparisons Initiative) and ANA4MIPS (Analysis for Model Intercomparisons Initiative) activities, using the Earth System Grid Federation for data exchange. WDAC has also asked GEWEX to produce a short white paper on the best practices for data quality assessment.

WCRP Core projects

CLIVAR (Climate Variability And Predictability)

Martin Visbeck and **Lisa Goddard** (co-chairs) presented recent CLIVAR activities and achievements. The International CLIVAR Project Office (ICPO) comprises seven staff, with headquarters in Southampton, UK, and several remote offices in other countries around the globe.

Over the past few years, CLIVAR has given careful consideration to evolving in a way to better meet the needs of its community. Its current mission is to improve understanding and predictability of ocean-atmosphere interactions and their influence on climate variability and change. CLIVAR's objectives include: understanding the causes of climate variability (on intraseasonal to centennial time scales) through observations, analysis, and model-

ling; improving predictions of climate variability and change attributable to internal as well as external processes; extending observational records, particularly of the ocean, by constructing quality-controlled data sets; and improving atmosphere and ocean components of Earth system models. CLIVAR plans to intensify cooperation with the marine biogeochemistry and ecosystem research communities. It also will expand support of education, capacity building, and outreach.

Martin Visbeck presented several highlights of CLIVAR research, particularly from its regional activities, which have strongly helped to develop GOOS. CLIVAR works closely with the Working Group on Ocean Model Development, whose future research is aimed at improving understanding of models and their biases (including biogeochemistry and ecosystems), high resolution modelling including coastal modelling, sea level and ocean interactions with ice sheets, the role of the ocean in decadal variability (including the Atlantic Meridional Overturning Circulation), as well as certain aspects of operational oceanography and data assimilation.

CLIVAR will establish or reconstitute the following groups to address their major objectives:

- Ocean Model Development Panel
- Global Synthesis and Observations Panel
- Atlantic Region Panel
- Pacific Region Panel
- Indian Ocean Region Panel
- Southern Ocean Region Panel
- Knowledge Exchange and Capacity Development Panel
- Monsoon Panel
- Expert Team on Climate Change Detection and Indices.

CliC (Climate and Cryosphere)

Jenny Baeseman (CliC IPO director) reported on CliC on behalf of Greg Flato (CliC chair). In 2013, a 5-year contract was signed between WCRP and the Norwegian Polar Institute, which continues to host the CliC IPO. CliC also has joint activities with the IASC (International Arctic Science Committee) and SCAR (Scientific Committee on Antarctic Research, a co-sponsor of CLIVAR). CliC operates two sea-ice working groups, the Antarctic Sea-Ice Processes and Climate Group (co-sponsored by SCAR) and the CliC Arctic Sea-Ice Working Group. CliC is supporting an Arctic sea-ice measurement campaign coordination tool and, in cooperation with the International Arctic Research Center, a mechanism for the standardization of sea-ice observations.

At its ninth SSG meeting several new CliC research foci were discussed: West Antarctic glacier-ocean modelling, understanding linkages between cryosphere elements, coordination of cryosphere observations for model evaluation and prediction initialization, Arctic freshwater system synthesis, ice-sheet model intercomparisons, an Arctic climate scenarios information archive and delivery, historical permafrost simulations merged with remote sensing, water availability from mountain glaciers and their response to climate change, and finally, the establishment of several new forums on ice-sheet modelling, sea-ice and climate, as well as permafrost modelling, some of which are already very active. The West Antarctic glacier-ocean modelling group, for example, will run state-of-the-art regional scale simulations to produce estimates of sea level based on the West

Antarctic ice sheet, allowing for in-depth model intercomparisons. The Arctic freshwater synthesis (jointly developed with IASC) will study different Arctic fresh water sources, fluxes, and storages; all of which could be very important because of the biogeophysical and socioeconomic consequences in the region and for the globe. CliC will profit from the earlier work of Jenny Baeseman, founding executive director of the Association of Polar Early Career Scientists (APECS), a large and vibrant network. CliC is also active in the development of WCRP's communication strategy.

GEWEX (Global Energy and Water Exchanges)

Kevin Trenberth, chair, presented the GEWEX (which now stands for 'Global Energy and Water Exchanges') report. The project has significantly reviewed its scope and mission, which is to measure and predict global and regional energy and water variations, trends, and extremes (heat waves, floods, and droughts) through improved observations and modelling of land, atmosphere, and their interactions, thereby contributing to the scientific basis of climate services. The work of GEWEX is based on the following components:

- The GEWEX Data and Assessments Panel, covering work on radiative processes and transfer codes, global data sets, support of observing systems (radiation and soil moisture), assessments, and intercomparison studies. The most recent assessments covered radiative fluxes and global satellite cloud data sets.
- GASS focuses on atmospheric and boundary layer studies, *i.e.* clouds, convection, microphysics, model parameterization evaluation

and development, as well as related data sets, tools, and intercomparisons.

- The Global Land/Atmosphere System Study (GLASS) aims to promote community activities that improve estimates and model representation of land surface state variables, understanding of land-atmosphere feedbacks, and the role of the land surface in climate predictability.
- The GEWEX Hydroclimatology Panel focuses on producing global and regional data sets of water and the energy cycle, which need to be made available at global data centres for hydrological applications, forecasting, as well as drought monitoring. The links between *in situ* observations, modelling, and Earth observational data are vital, as is the need to address the GEWEX science questions on a regional scale.

SPARC (Stratosphere-troposphere Processes And their Role in Climate)

The SPARC report was presented by its co-chairs **Joan Alexander** and **Greg Bodeker**. They started by reminding the JSC that the project's mandate was recently extended to include those aspects of tropospheric chemistry and dynamics that have links to the stratosphere. Currently SPARC's main themes are: detection, attribution, and prediction of stratospheric change; chemistry-climate interactions; and, stratosphere-troposphere dynamical coupling.

SPARC's approach for selecting research foci is based on several principles. A SPARC activity should contribute to WCRP priorities, respond to the needs of assessments (*e.g.* WMO/UNEP Ozone and IPCC

assessments), meet the requirements of users of SPARC science, and seek emerging talent. SPARC intends to ensure that its activities remain focused by defining clear deliverables and timelines facilitated by dedicated workshops and the involvement of a broad research community. The project is also actively involved in promoting its science to national agencies with the aim of defining research priorities and the broad communication of major outcomes, through, for example SPARC newsletters and the SPARC annual report.

The short presentation of individual activities covered, for example, phase two of the ESA-SPARC initiative, which aims to improve the quality of existing measurements to produce new stratospheric climate data records; the SPARC Data Requirements Initiative, which focuses on defining the types and quality of measurements needed by SPARC, but which simultaneously serves as input to WDAC, GCOS, CEOS, and space agencies; and, the Chemistry-Climate Initiative, which is a new collaborative project between IGAC (International Global Atmospheric Chemistry) and SPARC, covering modelling of both the troposphere and stratosphere.

SPARC will contribute to several of the WCRP Grand Challenges. The DynVar activity will contribute to the 'Regional climate information' Grand Challenge through assisting with identifying and studying phenomena that offer some degree of intraseasonal to interannual predictability. SPARC's Stratospheric Network for the Assessment of Predictability activity also directly addresses the sources and limits of predictability, and could also contribute to this Grand Challenge. SPARC's

participation in WGCM should also be useful for identifying key model errors that limit prediction skills. Furthermore, SPARC's contribution to WGSIP (see below) will also be useful for this Grand Challenge. For the Grand Challenge on 'Clouds, circulation, and climate sensitivity', SPARC's expertise on stratospheric drivers of changes in large-scale circulation systems will contribute to the understanding of climate and hydrological sensitivity, as well as by improving the representation of the coupling between cloud processes and large-scale dynamics.

SPARC is developing a strategy for its capacity building activities. This was further discussed at SPARC's fifth General Assembly, which took place in Queenstown, New Zealand, from 12-17 January 2014; one of the project's most important events. The conference covered the following scientific topics: atmospheric chemistry, aerosols and climate; stratosphere-troposphere-ocean dynamics and predictability of regional climate; coupling to the mesosphere and upper atmosphere; observational data sets, reanalyses, and attribution studies; and tropical processes.

Science presentations by the host nation

Paulo Nobre (National Institute for Space Research, INPE) showed the results of numerical simulations studying the South Atlantic Convergence Zone and its connection with sea surface temperature-driven climate variations. **Edmo Campos** presented the results of a study on the potential role of leakage of waters from the Indian Ocean into the South Atlantic ("Agulhas leakage") on the strength of the Atlantic Meridional Overturning Circulation.

Pan-WCRP modelling groups

Gerald Meehl presented the report on WGCM (Working Group on Coupled Modelling), starting by mentioning WGCM's main aims and then continuing to discuss CMIP5 and some of its results. CMIP5 has provided not only a vast amount of data, but also a wide variety of new climate change information, allowing the study of carbon-climate feedbacks, tropical cyclones using high-resolution time slices, decadal climate predictions including short-term climate changes and possible climate shifts (e.g. the early 2000s hiatus in global warming trends), paleoclimate simulations, and the analysis of cloud-climate feedbacks. Despite the higher complexity of the new generation of Atmosphere-Ocean Global Climate Models and Earth System Models, the spread of projections was comparable to CMIP3. Some quantities showed significant improvements compared to CMIP3, for example, the rate of Arctic sea-ice loss, reduction in cloud brightness, representation of the MJO (Madden-Julian Oscillation), while several other problems remain, for example, the double ITCZ, Arctic clouds and circulation, or the representation of Antarctic sea-ice. WGCM proposed having regular model analysis workshops to support the analyses of CMIP5 results.

WGCM has already started the planning process for CMIP6 so as to have continuity with CMIP5 and allow enough time to properly develop the CMIP6 experiment protocol. CMIP6 will have an experimental approach similar to CMIP5 and involve the same multiple communities that contributed to CMIP5. The decoupling of CMIP from IPCC was discussed, but the merit of having state-of-the-art models available for the IPCC assessments was

mentioned as a vital consideration to keep in mind.

Adam Scaife (also on behalf of the other co-chair Francisco Doblas-Reyes) reported on the activities of WGSIP (Working Group on Seasonal to Interannual Prediction). The main focus of WGSIP is to produce skilful regional climate prediction information from months to years ahead. This is clearly relevant for the WCRP 'regional climate information' Grand Challenge. Many WGSIP members are involved in real-time climate services, producing seasonal forecasts for use in real-time multi-model, long-range ensemble predictions and distributing them as WMO Global Producing Centres (available through the dedicated WMO Lead Centre).

Over the past year, the Climate Historical Forecast Project, a flagship WGSIP project, has created a key database for regional forecast research, which is hosted by the Centro de Investigaciones del Mar y la Atmosfera, based in Argentina. This database includes hindcast (or reforecast) experiments from 13 of the world's leading seasonal forecast systems, with more being added with time. Three WGSIP sub-projects on the role of land surface, sea-ice, and the stratosphere are progressing well, with several peer-reviewed papers in preparation. WGSIP is also planning an update of the CMIP decadal prediction protocol in collaboration with WGCM and CLIVAR.

Christian Jakob presented the report on WGNE (Working Group on Numerical Experimentation), which is chaired by Andy Brown and Jean-Noel Thepaut and jointly sponsored by WCRP and the WMO Commission for Atmospheric Sciences. WGNE's main aim is to foster the development

of atmospheric circulation models for weather prediction and climate studies on all time scales. The group coordinates several international numerical experimentation projects such as Transpose-AMIP (Atmospheric Model Intercomparison Project).

The following future activities are anticipated:

- Contribution to Earth system prediction, whereby weather models will be coupled to new components such as the ocean, air quality, hydrology, cryosphere, *etc.* This will require dialogue between several different communities.
- Short-range weather prediction focused on weather phenomena such as clouds, rain, and surface temperature, which require increased model resolution.
- ‘Traditional model development’ to study key model problems, such as boreal intra-seasonal variability, the ‘grey zone’ between scales of convection (resolved *vs.* parameterized), model dynamical cores, the stratosphere, *etc.*

WCRP partnerships and joint initiatives

Gilbert Brunet presented the S2S (Sub-seasonal to Seasonal Prediction) project on behalf of its two co-chairs, Frédéric Vitart and Andrew Robertson. The S2S project, a joint activity between the WWRP and WCRP, is aimed at improving forecast skill and process understanding on sub-seasonal to seasonal time scales, particularly related to high-impact weather events; promoting the initiative within operational centres and the applications community; and, making use of the expertise of the weather and climate research

community to address problems relevant to GFCS. Producing sub-seasonal to seasonal forecasts is particularly challenging because it is both an atmospheric initial condition problem and a boundary condition problem, usually involving more degrees of freedom than in seasonal prediction. Some sub-seasonal predictability is associated with the MJO, sea surface temperatures, sea-ice, snow cover, soil moisture, and stratospheric initial conditions. S2S sub-projects will concentrate on monsoons, the MJO, predictions for Africa, verification, as well as prediction of extreme events. A few case studies will be performed to demonstrate the benefit of sub-seasonal predictions for society. S2S will contribute to GFCS and will continue its collaboration with CLIVAR, GEWEX, WGNE, and connect with SPARC’s SNAP activity in the coming year.

Greg Bodeker presented the PCPI (Polar Climate Predictability Initiative) on behalf of its co-leaders Cecilia Bitz and Ted Shepherd. The implementation plan covers six proposed initiatives: (1) improving knowledge and understanding of past polar climate variations (up to 100 years), (2) assessing reanalyses in the polar regions, (3) assessing the performance of CMIP5 models in the polar regions, (4) improving our understanding of polar climate predictability on seasonal to decadal time scales, (5) ‘model error’, and (6) improving understanding of how jets and non-zonal circulation couple to the rest of the system in the Southern Hemisphere. The latter three initiatives will be carried out jointly with the WWRP-PPP (Polar Predictability Project). Instead of a steering committee, two ‘champions’ have been identified for each initiative, who are responsible for carrying them forward.

Adrian Simmons spoke about GCOS (Global Climate Observing System), whose work encompasses the climate components of most of the global observing system. GCOS assesses and communicates requirements for climate observations and related products, supports implementation, reviews progress, and reports to its sponsors and the UNFCCC. GCOS has started producing a report on the progress and adequacy of climate observations, scheduled for 2015, as well as a new Implementation Plan, due in 2016. GCOS sponsors have set up a review board to assess the added value of the GCOS programme, its mandate, and terms of reference, taking into account developments made since 1998, when the sponsors signed the GCOS memorandum of understanding. The observing system continues to evolve, with some concerns regarding the deterioration of some *in situ* networks, lack of progress in filling gaps in others, and limited provision for limb sounding and reference measurements from space. At the same time however, many improvements have been made, including the quantity and quality of observations from a wide range of platforms as well as the improvement of reanalyses.

José Marengo, a member of the IGBP (International Geosphere-Biosphere Programme) scientific committee, addressed the JSC on behalf of IGBP, whose strategic vision is to provide scientific leadership and knowledge of the Earth system to guide society onto a sustainable pathway during rapid global change. He presented several examples of how IGBP has contributed to international research on key biogeochemical processes. PAGES (Past Global Changes) has produced the first comprehensive global climate

paleo-reconstruction of the last two millennia. This regional-scale reconstruction indicates that the Medieval Climate Anomaly and Little Ice Age appear not to have been global phenomena. The Global Carbon Project (also affiliated with WCRP) quantitatively analysed global anthropogenic carbon dioxide emissions and found that actual emissions tracked the most carbon intensive scenario developed for the IPCC (RCP8.5), which, if continued to 2100, will result in average global temperature increases of between 4.0-6.1°C. IGAC coordinated a comprehensive analysis of black carbon (BC), concluding that BC is the second largest man-made contributor to global warming and also contributes to air pollution and related health problems. IGBP is presently engaged in producing a synthesis and a series of articles summarizing the challenges, highlights, and achievements of IGBP, as well as a discussion of future opportunities and perspectives of this type of research. The next stage for IGBP will be its transition into Future Earth, which will be finalized by December 2015.

Gilbert Brunet (chair of the WWRP JSC) started the WWRP discussion by outlining its long-term objectives, which are to

improve public safety and economic productivity by promoting research on the prediction of high-impact weather; improve weather forecasting of high-impact weather events by exploiting the advances made in scientific understanding, data assimilation, observational networks, and modelling techniques; improve understanding of atmospheric processes important for weather forecasting; and, maintain a strong focus on training opportunities for young scientists.

WWRP's activities are often collaborative and the programme's 2009-2017 implementation plan integrates the WMO member activities into particular themes. THORPEX (The Observing System Research and Predictability Experiment, the largest WWRP project to date) will run until the end of 2014, after which its activities will be continued through the S2S, PPP, and the High-Impact Weather prediction projects. PPP is the hourly to seasonal prediction research component of the WMO Global Integrated Polar Prediction System, and covers a broad range of topics including observations, data assimilation, modelling, ensemble forecasts, predictability and diagnostics, teleconnections, as well as societal and economic research applications. Several PPP

research activities will be conducted jointly with PCPI (see above). PPP is expecting to take advantage of the Year of Polar Prediction (YOPP), which is planned for 2017-2018. YOPP plans include an intensive observational and modelling period for improving polar prediction, research into forecast-stakeholder interactions, enhanced model verification, and education of students and early career scientists, for example, through APECS.

Concluding Session and next JSC meeting

Tony Busalacchi warmly thanked the hosts as well as all participants, especially the new JSC members, for the successful meeting. The JSC agreed that its 35th meeting will take place in Heidelberg, Germany, from 30 June to 4 July (including one day overlap with the 16th Session of the WMO Commission for Climatology), before the session was closed.

[The full meeting report is available as WCRP Report No. 22/2013 www.wcrp-climate.org/images/documents/reports_flyers/WCRP_JSC34_report.pdf].



The SPARC Activity

“Lifetime of halogen source gases”

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The SPARC Activity “Lifetime of halogen source gases” was launched at the 2011 SPARC Scientific Steering Group (SSG) meeting held in Pune, India. It culminated in the December 2013 publication of the WCRP – 15/2013 SPARC Report No. 6: “Lifetimes of Stratospheric Ozone-Depleting Substances, Their Replacements, and Related Species”. The report provides values for lifetimes and their uncertainties, an assessment of different lifetime definitions (*e.g.* steady-state *vs.* instantaneous lifetimes), and an estimate of lifetime changes resulting from the changing climate. Lifetimes from this report are being used in the 2014 Ozone Assessment to address various issues, such as estimation of global emissions, trajectories of ozone depleting substances (ODSs) into the 22nd century, and expected return dates to the 1980 benchmark level for ozone depletion.

Motivation

The concept of using lifetimes to relate atmospheric burdens to emissions has proven useful for quantifying the effects of ODSs and their replacements on ozone and climate. A study by Kaye and Penkett (1994) was the first focused effort to assess the lifetimes and associated uncertainties of ODSs. The 1998 WMO/UNEP Ozone Assessment Report (WMO, 1999) made use of the results, and

subsequent Reports (WMO, 2003; WMO, 2007) have mostly provided updates of just the lifetime values. WMO (2011) concluded that the lifetimes of some ODSs (*e.g.* CFC-11 and CCl₄) were probably longer than previously accepted. The community expressed the desire for a new evaluation because of tremendous model advancements, and a wealth of additional measurement data from ground-based stations, balloon and aircraft platforms, and satellites.

This re-evaluation is the first attempt in nearly two decades to estimate atmospheric lifetimes and uncertainties of ODSs and related substances using state-of-the art analysis techniques. It includes several replacement compounds that were not in use at the time of Kaye and Penkett (1994). For the illustration of historic efforts in assessing atmospheric lifetimes, best estimates and uncertainties of CFC-11 and CFC-12 lifetimes are shown in **Figure 1** together with the SPARC report’s new estimates of 52 and 102 years, respectively.

Approach

The SPARC “Lifetime of halogen source gases” activity’s final report was prepared by an international team of scientists comprising four coordinating lead authors, eight lead authors, and approximately 40 co-authors and contributors. In

addition, 10 principal reviewers worked with the lead authors to respond to mail review comments provided by over 30 reviewers. The final draft of the report was discussed at a review meeting in Zürich, Switzerland, held in January 2013.

The report consists of six chapters:

1. **Introduction:** The first chapter provides the motivation for the re-evaluation of the lifetimes and the justification for selection of the 27 species that were evaluated. **Table 1** shows the compounds together with their global abundances, their previous lifetime estimates, and their selection criteria.
2. **The Theory of Estimating Lifetimes Using Models and Observations:** This chapter provides an overview of the theory of estimating lifetimes using models and observations.
3. **Evaluation of Atmospheric Loss Processes – an update of the kinetic data that determine lifetimes:** This chapter re-evaluates rate coefficient and absorption cross-section data. Estimated uncertainties in the recommended parameters were reduced.
4. **New Inferred Lifetimes from Observed Trace-Gas Distributions:** Stratospheric lifetimes are derived using observed distributions of trace gases in the stratosphere and

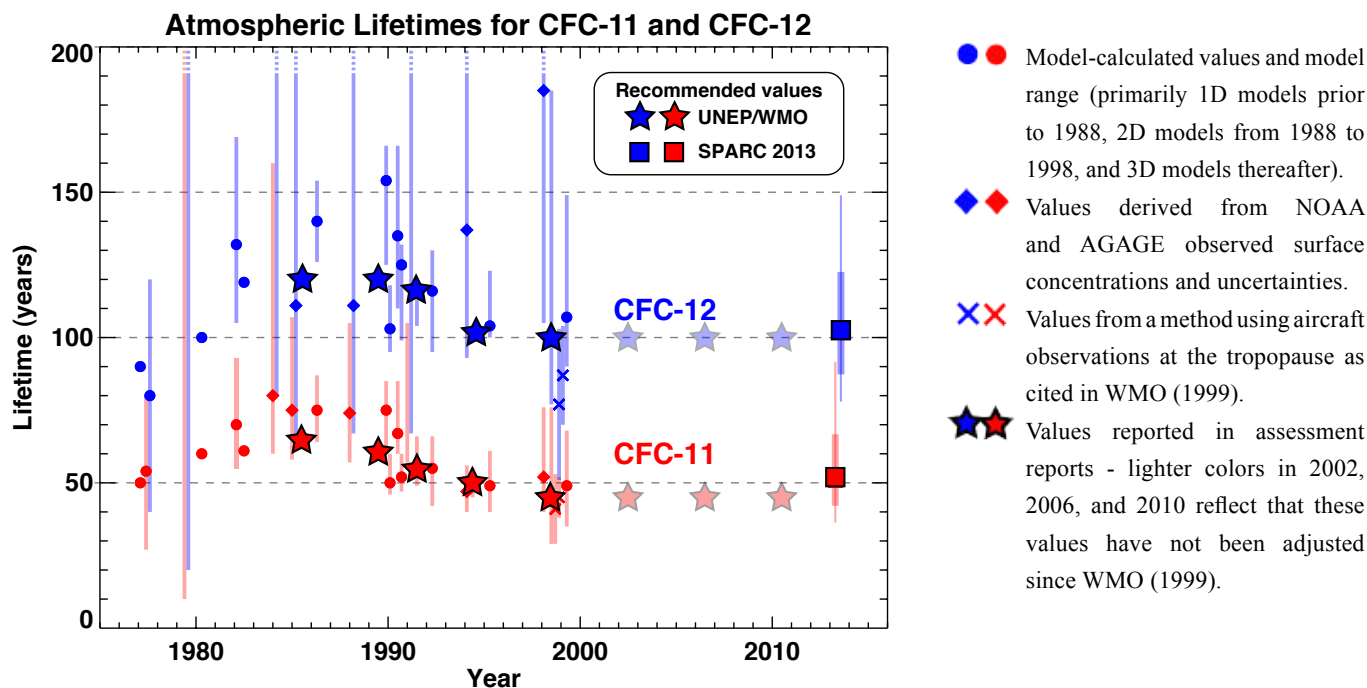


Figure 1: Lifetime estimates from various reports between 1976 and 2013 for CFC-11 (red) and CFC-12 (blue). Uncertainty estimates (or ranges) are shown as vertical bars (lifetimes without vertical bars did not include uncertainty estimates).

relative abundances of species near the tropopause. The observations are from aircraft, balloons, and satellites. In addition, atmospheric lifetimes are estimated by using a global box model that combined atmospheric trends with information on emissions.

5. Model Estimates of Lifetimes:

Steady-state lifetimes are derived using coupled chemistry-climate models (CCMs). Most models had been previously evaluated under the SPARC CCMVal activity (SPARC, 2010).

6. **Summary:** In the final chapter, estimates for steady-state atmospheric lifetimes and their uncertainties from the various chapters are combined into a set of recommended values.

Method

Five individual methods were used to derive lifetimes (global atmospheric lifetime and steady-state lifetime) and resulting individual estimates

were combined for a best estimate of lifetimes and uncertainties.

1. The inverse technique used a 12-box model to retrieve the global atmospheric lifetime from the time series of observed atmospheric burden (derived from surface concentrations) and global emissions. This method does not require detailed knowledge of the chemical properties of the molecule, but the information was useful for choosing an *a priori* value in the inversion process and in relating burden to surface concentration. The retrieved lifetime values could be used in the same 12-box model in the forward mode to compute steady-state lifetimes. This method was used to derive lifetimes for CFC-11, CFC-12, CFC-113, and CH_3CCl_3 .
2. A satellite hybrid method used vertically resolved concentrations of the species in the stratosphere and model-derived photolysis loss rates to derive global lifetimes. This

- method is useful for species that are mainly removed in the stratosphere. The calculated values could be adjusted to approximate the steady-state lifetimes. This method was used in the report to derive lifetimes for CFC-11, CFC-12, and N_2O .
3. The tracer-tracer correlation method used simultaneously observed concentrations of a pair of species in the stratosphere (either *in-situ* or satellite) to determine relative stratospheric lifetimes. Data were available for CFC-11, CFC-12, CFC-113, CCl_4 , N_2O , H-1211, H-1301, CH_3CCl_3 , CH_3Cl , CH_4 , HCFC-22, HCFC-141b, and HCFC-142b. A stratospheric lifetime for CFC-11 is required to estimate the absolute lifetimes.
4. Estimated tropospheric OH abundance is a by-product of the inverse modelling retrieval when applied to CH_3CCl_3 . The partial lifetime due to OH loss in the troposphere for other hydrogen-containing species

Table 1: The list of 27 species evaluated in SPARC (2013), with previous lifetimes and 2008 global mixing ratios (WMO, 2011). Bold fonts represent high priority species.

Name	Formula	Lifetimes from WMO (2011)	Mixing Ratio in 2008	Remarks
<i>Primarily stratospheric removal</i>				
CFC-11	CCl ₃ F	45 yr	244.1 ppt	Long-lived ODS, reference for ODP, chlorine source gas
CFC-12	CCl ₂ F ₂	100 yr	536.5 ppt	Long-lived ODS, chlorine source gas
CFC-113	CCl ₂ FCClF ₂	85 yr	76.9 ppt	Long-lived ODS, chlorine source gas
CFC-114	CClF ₂ CClF ₂	190 yr	16.4 ppt	Long-lived ODS, chlorine source gas
CFC-115	CClF ₂ CF ₃	1020 yr	8.4 ppt	Long-lived ODS, chlorine source gas
CCl₄	CCl ₄	35 yr	89.8 ppt	Long-lived ODS, chlorine source gas
Nitrous oxide	N ₂ O	114 yr	321.6 ppb	Natural and anthropogenic sources Greenhouse gas, odd-nitrogen source gas
Halon-1211	CBrClF ₂	16 yr	4.2 ppt	Long-lived ODS, bromine source gas
Halon-1301	CBrF ₃	65 yr	3.2 ppt	Long-lived ODS, bromine source gas
Halon-2402	CBrF ₂ CBrF ₂	20 yr	0.5 ppt	Long-lived ODS, bromine source gas
Nitrogen trifluoride	NF ₃	500 yr	0.45 ppt	Greenhouse gas
<i>Primarily tropospheric removal</i>				
Methane	CH ₄	8.7yr/12.0 yr ^a	1781.3 ppb	Natural and anthropogenic sources Greenhouse gas, odd-hydrogen source in the atmosphere
Methyl chloroform	CH ₃ CCl ₃	5 yr	10.9 ppt	Long-lived ODS, chlorine source gas
Methyl chloride	CH ₃ Cl	1.5 yr	546.0 ppt	Mainly natural sources, chlorine source gas
Methyl bromide	CH ₃ Br	1.9 yr	7.4 ppt	Natural and anthropogenic sources, bromine source gas
HCFC-22	CHClF ₂	11.9 yr	191.5 ppt	CFC replacement, chlorine source gas
HCFC-141b	CH ₃ CCl ₂ F	9.2 yr	19.4 ppt	CFC replacement, chlorine source gas
HCFC-142b	CH ₃ CClF ₂	17.2 yr	18.7 ppt	CFC replacement, chlorine source gas
HFC-23	CHF ₃	222 yr	21.8 ppt	Mainly a by-product in HCFC-22 production
HFC-32	CH ₂ F ₂	5.2 yr	2.7 ppt	ODS replacement
HFC-125	CHF ₂ CF ₃	28.2 yr	6.1 ppt	ODS replacement
HFC-134a	CH ₂ FCF ₃	13.4 yr	47.9 ppt	ODS replacement
HFC-143a	CH ₃ CF ₃	47.1 yr	8.5 ppt	ODS replacement
HFC-152a	CH ₃ CHF ₂	1.5 yr	5.9 ppt	ODS replacement
HFC-227ea	CF ₃ CHF ₂ CF ₃	38.9 yr	0.45 ppt	ODS replacement
HFC-245fa	CHF ₂ CH ₂ CF ₃	7.7 yr	1.0 ppt	ODS replacement
Halon-1202	CF ₂ Br ₂	2.9 yr	0.03 ppt	Long-lived ODS, bromine source gas

^aTotal lifetime/pulse decay lifetime from IPCC (2007)

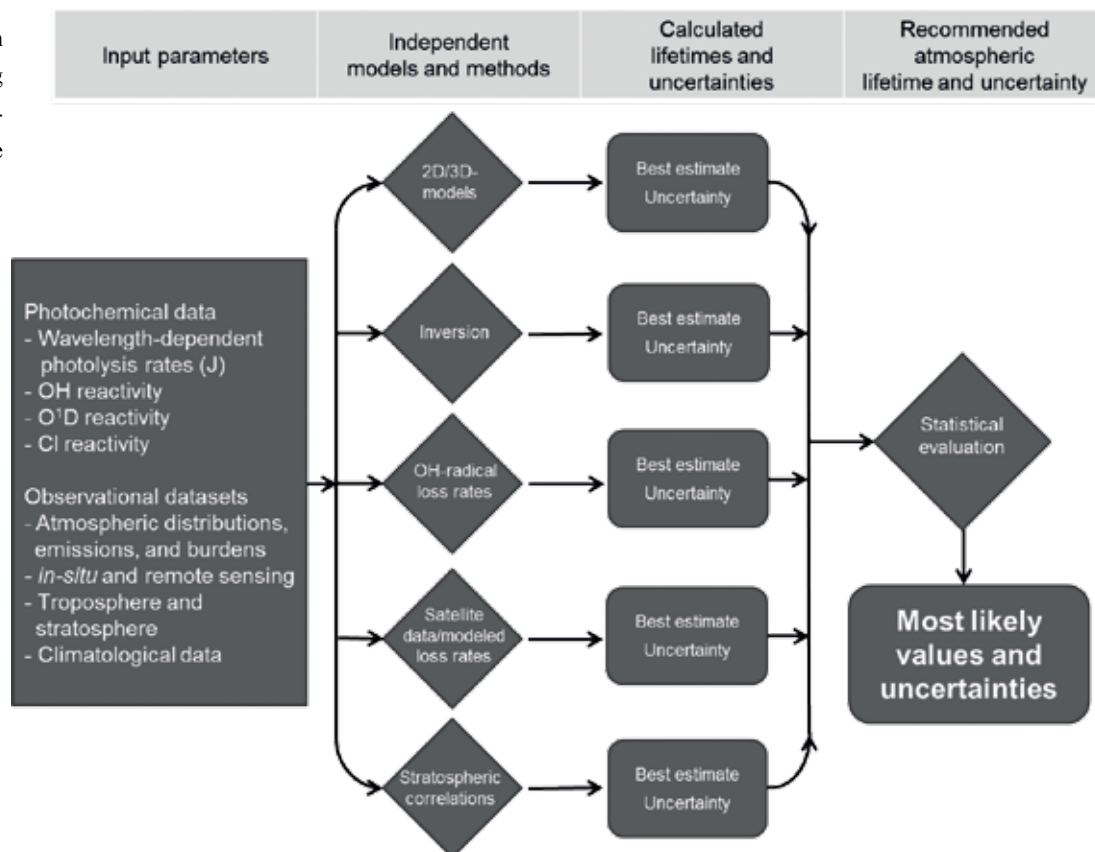
(e.g. HCFCs and HFCs) was then computed using the 12-Box Forward Model. The partial lifetime was then combined with other information to obtain steady-state lifetimes.

- One 2D and six 3D models were used to derive lifetime estimates. Model lifetimes were calculated for a particular climate (e.g.

present day composition and meteorology) based on the current global budgets, with corrections for being out of steady-state. In the modelling studies, the focus was on lifetime as defined by photochemical reactions occurring in the atmosphere. Effects on removal by deposition (to land or ocean)

are added afterward as a partial lifetime. CCMs have improved tremendously since the 1994 lifetimes assessment (Kaye and Penkett, 1994). While these models do not directly make use of atmospheric trace gas measurements, observations of many species were used to guide the development and

Figure 2: Information flow chart for producing recommended steady-state atmospheric lifetime values and uncertainties.



provide evaluation metrics for the models.

The flow of information on how the lifetime values from the various methods were combined to a single recommended value and the associated uncertainty is explained in **Figure 2**. We treated the value from each method as an estimator of the recommended steady-state lifetime. For observation-based methods (1-4), individual estimates arise when different data sets are used to derive the lifetime. The estimate for the model-based method (5) is the mean of the individual models. Through analyses of the methodology and by propagating the uncertainties of the input data, we derive an associated uncertainty estimate for each method. The best estimates from each method (the estimators) are then combined using an uncertainty-weighted average to produce the recommended lifetime. Two ranges for the recommended lifetime uncertainties are provided (both are 2σ). The first range is the weighted mean of the variances

from each method, taking into account the covariance between estimators. This provides the range for the “most likely” values. The second corresponds to the joint distribution of the individual variances around the arithmetic (*i.e.* unweighted) mean of the estimators. This represents the “possible” range of the lifetime value estimates. The interpretation is that values outside of this second range are unlikely to be supported by future evaluations. A more thorough explanation of the method for deriving recommended lifetime estimates and uncertainties is provided in SPARC (2013).

Results

Table 2 lists the recommended values of steady-state lifetimes from SPARC (2013), and compares them with previous lifetimes from WMO (2011). Additionally, “most likely values” and “possible ranges” are given as measures of uncertainty. See SPARC (2013) for definitions of uncertainties

and further explanation for the levels of understanding. **Figure 3** graphically summarizes the steady-state lifetime estimates determined for the 27 species in comparison with previous estimates.

The new CFC-11 and CFC-12 recommended lifetimes are 52 and 102 years, respectively. The CFC-11 lifetime has increased by 7 years (15%), while CFC-12 has only increased by 2 years (2%). What is more notable is that while some previous assessments provided uncertainty estimates, we provide a full set of consistent uncertainties that combine the uncertainties into two ranges, as noted above, a “most likely” range and a “possible” range. For CFC-11 the possible range is 35–89 years, while the likely range is 43–67 years. Similarly, for CFC-12 the possible range is 78–151 years, while the likely range is 88–122 years.

For CCl_4 the recommended steady-state lifetime of 44 years is calculated only from the removal

Table 2: Recommended estimates for steady-state lifetimes (SPARC, 2013) and uncertainty ranges, compared with previous lifetimes from WMO (2011). See SPARC (2013) for further explanation of uncertainties and levels of understanding.

Species	τ [years] WMO (2011)	τ [years] SPARC (2013)	τ [years]				Level of Scientific Understanding
			Possible range				
				Most likely values			
CFC-11	45	52	35	43	67	89	High
CFC-12	100	102	78	88	122	151	High
CFC-113	85	93	69	82	109	138	Medium
CCl ₄	35	44	33	36	58	67	Medium
N ₂ O	114	123	91	104	152	192	High
Halon-1301	65	72	58	61	89	97	Medium
Halon-1202	2.9	2.5	1.5			7.3	Low
Halon-1211	16	16	10			39	Low
Halon-2402	20	28	20			45	Low
CFC-114	190	189	153			247	Low
CFC-115	1020	540	404			813	Low
Methyl Chloroform	5	5	4.7			5.4	High
HCFC-22	12	12	9.3			18	Medium
HCFC-141b	9.2	9.4	7.2			13.5	Medium
HCFC-142b	17.2	18	14			25	Medium
HFC-23	222	228	160			294	Medium
HFC-32	5.2	5.4	4			8.2	Medium
HFC-125	28.2	31	22			48	Medium
HFC-134a	13.4	14	10			21	Medium
HFC-143a	47.1	51	38			81	Medium
HFC-152a	1.5	1.6	1.2			2.2	Medium
HFC-227ea	38.9	36	25			61	Medium
HFC-245fa	7.7	7.9	5.5			14	Medium
NF ₃	500	569	454			764	Low
Methane	8.7/12	9.8	7.6			14	Medium
Methyl chloride	1.5	1.3	0.9			2	Medium
Methyl bromide	1.9	1.5	1.1			2.3	Medium

by photochemical reactions in the stratosphere (excluding ocean uptake and soil removal). This is 26% larger than the 35-year lifetime from recent WMO reports. Previously, the 35-year lifetime was combined with an oceanic removal lifetime of 94 years to obtain a total 26-year lifetime (WMO, 2011). That lifetime was found to be too short to reconcile the observed tropospheric trends with estimated emissions. The current estimate for the oceanic lifetime is 81 years, with a soil removal lifetime of 195 years. The combined lifetime is 25 years. Thus, while the atmospheric lifetime estimate has been improved, the CCl₄ budget discrepancy (Montzka and Reimann, 2011) remains unresolved.

The CCMs use JPL-10-6 photochemical data in their simulations for this report. However, there have been significant revisions in the photochemical data for some of the 27 species based on our Chapter 3. Most notably, new experimental data are evaluated for CFC-115, NF₃, Halon-1202, Halon-1211, and Halon-2402. These new data have been used to recompute lifetimes in a 2-D model. Lyman- α absorption cross-section recommendations, which have not been considered in previous evaluations, are also provided and uncertainties estimated. Lyman- α photolysis is shown to be a dominant mesospheric loss process, but makes only a minor contribution to most global lifetime estimates. To

correct errors in previously reported values, the ultraviolet absorption cross-section parameterizations for use in model calculations for CFC-11, CFC-12, CFC-113, CFC-114, HCFC-22, CH₃CCl₃, CH₃Cl, and CH₃Br are revised. The impacts on the computed lifetime are small, approximately a few percent. The estimated uncertainty in the hydroxyl radical, electronically excited atomic oxygen (O(¹D)), and atomic chlorine reaction rate coefficients given in the report are, in general, less than those given in the JPL10-6 (Sander *et al.*, 2011) and the IUPAC (Atkinson *et al.*, 2008) data evaluations.

Summary

The results of the SPARC “Lifetime of halogen source gases” activity are now published as a report: “Lifetimes of Stratospheric Ozone-Depleting Substances, Their Replacements, and Related Species” (SPARC, 2013). This activity has accomplished a number of significant tasks: 1) a refined discussion on the theory of lifetimes, 2) revisions to the photochemical database used to evaluate lifetimes, 3) new estimates and revisions of lifetimes based on observations, 4) lifetime estimates from modern CCMs, and 5) a combined set of recommended lifetimes based upon these new estimates (Table 2 and Figure 3).

Empirical estimates of ozone depletion potentials and global warming potentials are based upon accurate lifetime estimates. Furthermore, future levels of ODSs and climate gases are also highly dependent on lifetimes. Hence, the impact of these lifetime revisions will be addressed in the 2014 WMO/UNEP Ozone Assessment report, as lifetimes affect our metrics of both ozone depletion and climate change,

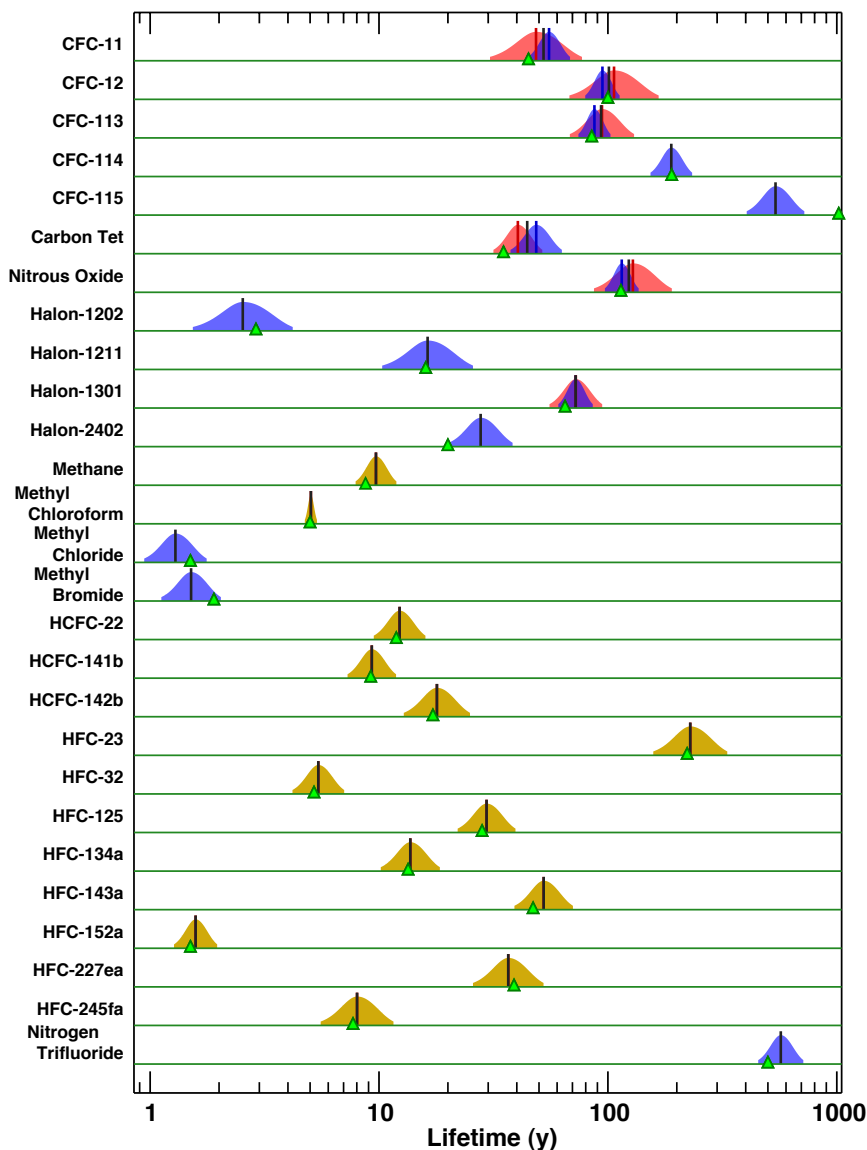


Figure 3: Recommended steady-state lifetime estimates (vertical black lines), lifetime estimates from models (blue lines), and observations (red lines). The estimated probability density functions of uncertainties from models (light blue) and observations (light red) are also shown. The uncertainty estimates for the HCFCs and HFCs (shown in yellow) are from the uncertainty in the retrieved OH concentration and uncertainties in the reaction rate constants. Lifetime estimates from previous reports (WMO, 2011; IPCC, 2007) are indicated by the green triangles.

as well as recovery dates for the return of ozone to 1980 levels.

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IUPAC Task Group on Atmospheric Chemical Kinetic Data Evaluation

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The IUPAC Task Group on Atmospheric Chemical Kinetic Data Evaluation consists of internationally recognized experts from universities, government labs, and industry. It provides evaluated chemical data covering the atmospheric chemistry used in global, regional, and urban climate and air quality models. Over the past decade our evaluations have been published in the form of peer-reviewed articles as part of a special issue in Atmospheric Chemistry and Physics (ACP; http://www.atmos-chem-phys.net/special_issue8.html), with the most recent article providing evaluated data for heterogeneous reactions of atmospheric importance. Parallel to this, the Task Group continuously updates individual reactions on our website, which has recently moved to the ETHER site maintained by CNRS-Paris <http://iupac.pole-ether.fr/>.

Historical remarks

First established as the CODATA Task Group on Chemical Kinetics, the IUPAC sub-committee for Gas Kinetic Data Evaluation for Atmospheric Chemistry started its work 1977 in response to the need for an internationally-assessed data set for modelling the impact of anthropogenic pollutants on tropospheric and stratospheric composition. Later sponsored by IUPAC, the group continuously expanded and updated

its evaluations in a series of nine peer-reviewed articles in the Journal of Physical and Chemical Reference Data. The recent move to publish the evaluations in ACP complied with the needs of the community for open access evaluations. The expansion of the group's activities to heterogeneous processes has led to the name change, now the Task Group on Atmospheric Chemical Kinetic Data Evaluation, reflecting the broader scope of evaluations.

Data evaluation

It is essential that atmospheric chemistry models contain up-to-date chemical mechanisms so as to provide the required accuracy and facilitate comparison of results between different models. It is also important that global chemistry transport models as well as climate and Earth system models contain suitable mechanisms in a simplified form derived from the detailed mechanism. The results of laboratory experiments, which provide the kinetic and mechanistic data necessary to describe chemical transformations in the atmosphere, are not always conclusive, especially if results from different research groups using different methods are available. The use of laboratory data therefore requires a substantial effort of compilation, review, and assessment before preferred or recommended values can be made

available to the atmospheric science community.

By providing a detailed evaluation and preferred parameterizations, activities such as performed by this IUPAC Task Group and the NASA-JPL panel go further than compilations of rate coefficients and products. See Cox (2012) for an extensive review of data evaluation in atmospheric chemistry.

The evaluation process itself starts with a consideration of the degree to which experimental data can be applied to atmospheric conditions of concentration, pressure, and temperature. Next, an assessment of the experimental procedures is performed, followed by a comparison of the results obtained by different experimental approaches and reported by different groups. The data set as a whole then provides the basis for preferred values of a given process and for estimates of the statistical errors and uncertainties. In order to make such evaluations, the panel members draw on extensive experience from their own research groups in using (and evaluating data from) the many experimental methods that have been applied.

The evaluations by the IUPAC Task Group on Atmospheric Chemical Kinetic Data Evaluation have evolved along with developments

Figure 4: The IUPAC Task Group on Atmospheric Chemical Kinetic Data Evaluation on the occasion of a recent meeting held in Paris, France, November 2013. From left to right: John Crowley, Jürgen Troe, Markus Ammann, Tony Cox, Tim Wallington, Mike Jenkin, Wahid Mellouki, Missing: Michel Rossi.



in atmospheric chemistry over the past 50 years. Initially driven by the early accounts of photochemical processes in the gas phase that control stratospheric ozone chemistry and air pollution in the troposphere, the level of detail and knowledge has expanded enormously, and has also led to community-wide agreement of how the kinetics of gas phase chemical reactions and photochemical processes should be described and parameterized. This facilitated the establishment of a framework for the data evaluation and dissemination activities of the IUPAC group. Currently the Task Group is furthering this process by providing recommendations on the website in machine-readable format to allow online updating of models with the most recent recommendations.

Latest developments on heterogeneous processes

The recognition of the importance of heterogeneous processes with aerosol particles in both the stratosphere and the troposphere for gas phase chemistry, aerosol composition, as well as their effects on climate and human health has led to parallel efforts in establishing suitable descriptions and parameterizations for gas to particle conversion and reactions on the surface and within the bulk of particles. Over

the past decade these concepts have converged substantially (Kolb *et al.*, 2010), so that our evaluation activity could be expanded to cover heterogeneous processes of both solid and liquid particles. An important aspect is that these processes are presented in a homogenized way by defining the essential kinetic parameters irrespective of the physical properties of the substrate, such that solids and liquids are treated in the same way. This means that the evaluation of heterogeneous reactions has been entirely refurbished from previous evaluations and also goes beyond what other evaluations have provided. The results of these recent efforts are presented in the two most recent volumes of the series in ACP (Crowley *et al.*, 2010, covering processes on solid substrates such as ice, mineral dust, and acid hydrates; and Ammann *et al.*, 2013, covering processes on liquid substrates). Both volumes include a range of key reactions relevant to the upper troposphere and lower stratosphere, which are of obvious relevance to the SPARC community. Similar to their precursors dealing with gas phase reactions, these volumes start with the presentation of summary tables that provide an overview of the systems evaluated and some of the essential kinetic parameters. This is followed by a detailed description of the kinetic and thermodynamic framework,

which forms the basis of the evaluation. This section also includes further detailed descriptions of relevant information pertaining to the substrates, which is of particular relevance for the description of the properties of sulfuric acid solutions under upper tropospheric and lower stratospheric conditions. For each of the non-reactive or reactive processes considered, a datasheet is presented in the form of appendices that follow the format of our earlier gas phase reaction evaluations.

For historic reasons, many heterogeneous reactions were studied following the discovery of the causes of the polar stratospheric ozone hole. Since then, several conceptual and experimental developments have been made. In the context of evaluating the processes in cold sulfuric acid solutions, the most recent descriptions of thermodynamic solution properties have been taken into account. Overall, this required the reanalysis of some of the original kinetic data and led to a revision of kinetic parameters compared to the original reports in several cases. This underlines the value of such evaluation work in providing the best possible state of knowledge to the atmospheric science community.

The website

Since 1999, the group has maintained a website that was initially hosted in Cambridge and has recently been moved to the ETHER site, maintained by CNRS-Paris (<http://iupac.pole-ether.fr/>). The main aim of the website is to provide the most up-to-date datasheets and summary tables to the atmospheric science community. Apart from the datasheets being available for download, the website also provides corresponding guides to the datasheets and options to search for specific reactions or

recent updates. Individual users may subscribe to an RSS feed or a mailing list to be kept informed about updates to the database.

The website is updated as new data on reactions from past published volumes become available. The headers of the data sheets provide a record of when the reaction was last reviewed or the last change to the recommended values was made. As an example, consider the reaction of HO with NO₂. This is an unusually important reaction in ozone chemistry as it is a vital removal process for both species, which are active in ozone formation. It produces a relatively inert (from an ozone chemistry point of view) product. This reaction appeared in Volume I of the ACP series in 2004. Important new results regarding this reaction recently became available and so the data sheet was updated and the new version posted on the web (http://iupac.pole-ether.fr/datasheets/pdf/NOx13_HO_NO2+M_I.A3.43.pdf).

A new feature to facilitate the usage of the datasheets is the provision of a single-line expression to parameterize pressure and temperature dependent gas-phase reactions that

can be copied directly into spreadsheets or other programs.

The website is also an important tool for keeping data sheets current. Researchers can visit the website and find the latest IUPAC recommendations based on the most recently published data. The IUPAC group is working with the CNRS to add functionality to the website, making it more interactive and facilitating the direct extraction of data from the website using machine-readable files.

Current and future activities

In addition to updating the >1000 data sheets on the website as new data become available, IUPAC is currently extending the gas-phase database to cover aspects of the degradation of large (> C4) biogenic and anthropogenic hydrocarbons (e.g. terpenes and aromatics). These species play important roles in tropospheric chemistry in rural and urban environments. The panel is also evaluating the available data for heterogeneous processes involving tropospheric organic aerosol and soot. The IUPAC Task Group welcomes comments and suggestions from the community

for ways to improve their efforts.

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Report on the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2013 Science Workshop

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Approximately 130 participants attended the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI, <http://www.pa.op.dlr.de/CCMI/>) 2013 Science Workshop, held in Boulder (CO), USA, at the Center Green Campus of the National Center for Atmospheric Research (NCAR) from 14-16 May 2013 (see **Figure 5**). The workshop was followed by a Scientific Steering Committee Meeting held on the morning of 17 May 2013. Workshop participants' expertise ranged from global chemistry and climate model developers and users, to *in situ* and satellite observational experts, with interests in tropospheric and stratospheric chemistry and climate. Science topics discussed included key observations needed for model evaluation to improve constraints on tropospheric and stratospheric chemistry and dynamics, as well as stratosphere-troposphere coupling. Examples of process-oriented evaluation of CCMs were presented and discussed.

There were three days of scientific talks and discussions, focusing on upcoming multi-model simulations and their analysis. The recorded videos and presentations from the workshop are available from the workshop website at <http://ccmi.ucar.edu/>. Three breakout groups

were held, targeting specific topics: (1) the CCMI data request and diagnostic tool, (2) tropospheric chemistry, and (3) CCMI support for the upcoming WMO/UNEP Scientific Assessment of Ozone Depletion (see details below). Throughout the meeting, upcoming CCMI multi-model analyses were discussed extensively. 23 different global chemistry-climate models are currently participating in the first round of CCMI simulations (see **Table 3**) and representatives from each of the modelling groups presented an update on the status and plans of their simulations and analyses. The CCMI Phase-1

(CCMI-1) simulations (Eyring *et al.*, 2013a) are being carried out partly in support of the 2014 WMO/UNEP Scientific Assessment of Ozone Depletion, and will also form an ensemble for a first comprehensive intercomparison of transient chemistry-climate hindcasts of the late 20th and early 21st century, spanning both the troposphere and stratosphere. Hindcast simulations will be used to constrain the models and facilitate detailed comparisons between models and observations, as well as process-oriented model evaluation. These simulations feed into the evaluation for assessing future



Figure 5: Participants of the IGAC/SPARC Chemistry-Climate Model Initiative (CCMI) 2013 Science Workshop that was held in in Boulder (CO), USA, at the Center Green Campus of the National Center for Atmospheric Research (NCAR) in May.

chemistry-climate projections. Model groups are producing output that will be uploaded to the British Atmospheric Data Centre (BADC), and distributed to the community for analysis.

Breakout Group 1: CCMI data request and diagnostic tool

This group met to discuss model output format, specifications, and timelines for the CCMI-1 data request, as well as possible pathways to make progress with a CCMI diagnostic tool for routine evaluation of the models.

The CCMI data request combines the output specifications from ACCMIP (Atmospheric Chemistry and Climate Model Intercomparison Project) and CCMVal-2 (Chemistry Climate Model Validation Activity), as well as additional requests from the CCMI simulation document (Eyring *et al.*, 2013a). Additional input requests to this table, as discussed at the workshop, and as further collected from the community (see updates on the CCMI website) are also included. Qi Tang

and Peter Hess (Cornell University, USA) have taken the lead in compiling this data request. A large emphasis in the first round of CCMI is placed on improving the comparability between models and observations (see also Eyring *et al.*, 2013a), so the data request includes additional output for improved comparison with aircraft and satellite data. Model simulations with specified meteorology also facilitate detailed comparisons with individual campaigns, not just climatologies. A first draft of the CCMI-1 data request was sent to the CCMI model groups and users in early July 2013 to collect comments on the feasibility for the model groups and possible missing output to be used for process-oriented analysis of the model simulations. The comments were then considered in the final data request, which is available on the CCMI website. Climate Model Output Rewriter (CMOR, see <http://www2-pcmdi.llnl.gov/cmor>) tables corresponding to this output are being created under the lead of Philip Cameron-Smith (PCMDI, USA), and will be available on the CCMI website soon.

The second part of the breakout group was devoted to discussions on the CCMI diagnostic tool. The existing Chemistry-Climate Model Validation Diagnostic tool (CCMVal-Diag, Gettelman *et al.* (2012)) forms the basis of the evaluation tool to be used in CCMI. The CCMVal-Diag tool is currently being further extended into an Earth System Model Evaluation tool (ESMValTool) in various projects, and, compared to the CCMVal-Diag tool, already includes many additional climate diagnostics and several technical improvements. The ESMValTool is a flexible and extensible open source package that facilitates the complex evaluation of global models. It is currently based on Python and the NCAR Command Language (NCL), but discussions in the breakout group called for the need to allow for other open source libraries (*e.g.* R, CDAT, Fortran) to be called. The tool can be used to evaluate single models (or different versions of a model), as well as multiple models from CCMI, the Coupled Model Intercomparison Project (CMIP), and other Model Intercomparison Pro-

Table 3: Chemistry-climate models currently participating in the first round of CCMI simulations:

	Model Name	Modeling Center
1	ACCESS	University of Melbourne, Australia, and NIWA, NZ
2	CCSRNIES-MIROC3.2	NIES, Tsukuba, Japan
3	CESM-Superfast	LLNL, USA
4	CESM1-CAM4Chem	NCAR, USA
5	CESM1-WACCM4	NCAR, USA
6	CICERO-OsloCTM3	CICERO, Norway
7	CMAM	EC (Environment Canada), Canada
8	CNRM-CCM	Météo-France, France
9	EMAC	Modular Earth Submodel System (MESSy) -Consortium (DLR, KIT, FZJ, FUB, UMZ, MPIC), Germany
10	GEOSCCM	NASA/GSFC, USA
11	GEOS-Chem	LAGEO, China
12	GFDL-AM3	NOAA-GFDL, USA
13	GISS-E2-R	NASA-GISS, USA
14	HadGEM3-ES	Hadley Centre, Met Office, United Kingdom
15	LMDZrepro	IPSL, France
16	MIROC-ESM-CHEM	NIES, Nagoya Univ., JAMSTEC, Japan
17	MOCAGE	GAME/CNRM, MétéoFrance, France
18	MRI-ESM1r1	MRI, Japan
19	NIWA-UKCA	NIWA, NZ
20	SOCOLv3	PMOD/WRC and IAC ETHZ, Switzerland
21	UIAQ-CCM	University of L'Aquila, Italy
22	UMSLIMCAT	University of Leeds, UK
23	UMUKCA-UCAM	University of Cambridge, UK

jects that use CMOR-formatted output. The tool is built in such a way that the code allows further extensions to be made by different users for different applications and types of Earth System Models. Several institutions have already joined the development of the ESMValTool as part of various projects in a version-controlled repository that is hosted at the German Aerospace Center (DLR) using Subversion. Subversion is a free and open source version control system, which manages files and directories, and the changes made to them (see <http://svnbook.red-bean.com/index.en.html>). The CCMI community is encouraged to help developing this evaluation tool by either joining the core development team or by contributing routines. In particular, it is hoped that those people who volunteered to lead a CCMI multi-model analysis (see http://www.pa.op.dlr.de/CCMI/CCMI_DataRequests.html) will contribute their codes to the tool to allow for future efforts to repeat these analyses, allowing further model evaluation and benchmarking.

Breakout Group 2: Tropospheric Chemistry

A clear set of chemistry-climate research themes emerged from the discussions in the tropospheric working group. These can be broadly summarized as: (1) understanding long-term trends and variability in tropospheric ozone, a major greenhouse gas and air pollutant; (2) exploring links between chemical constituents and climate variability (e.g. El Niño-Southern Oscillation (ENSO)); and (3) a deep exploration of the drivers of the hydroxyl radical (OH), a gas that influences concentrations of important greenhouse gases, such as methane and ozone. For these themes, observational datasets,

both satellite and *in situ*, have been identified to constrain and evaluate CCMI model simulations. The first phase of analysis will largely focus on the hindcast simulations (covering the period 1960-2010), identifying biases and determining whether constraints derived from observations can help to narrow the range of future projections.

A thorough exploration of 1960-2010 tropospheric ozone trends will provide insights into how changing ozone precursor emissions (natural and anthropogenic), together with changing climatic factors, have shaped our environment over the last five decades. For example, an analysis of long-term ozone trends at European sites with a focus on their seasonal variability was presented at the meeting, and the shortcomings in the current generation of models as well as the emissions used were identified. Can we use the CCMI models to understand and reduce this discrepancy?

Several participants proposed leading studies focused on the links between tropospheric composition and transport and climate dynamics. A natural first step is the relationship between tropical tropospheric ozone and ENSO, which has been explored in both satellite and *in situ* observations, and which is also a robust feature in tropospheric chemistry-climate models. The role of stratosphere-troposphere exchange on tropospheric ozone distributions and variability also received much attention. This process could become an increasingly important source of tropospheric ozone if precursor emission decreases are combined with stratospheric ozone recovery and an intensification of stratospheric circulation. The CCMI effort will also enable study of the links between air quality and large-scale atmospheric flow.

The challenge to understand OH rests on the shoulders of more than three decades of effort to understand its distribution and trends. This area will encompass a broad spectrum of proposed studies involving reconciling modelled and observed lifetimes and distributions of reactive constituent, clouds, and detailed analyses of high time-resolution model output. ACCMIP analyses revealed that models disagree on the sign of the OH trend both since the pre-industrial period and for the projected future. Determining the drivers of the trend was sometimes hampered by the available model diagnostics. A significant effort of the CCMI analysis will involve understanding the origin of this model diversity through targeted requests for detailed and relevant diagnostics.

A unifying thread for these research themes is to make a more thorough use of the wealth of observations available for model comparisons, including from ground-, aircraft-, and satellite-based platforms. The CCMI community welcomes observational scientists and there has been a great effort to compile measurement data from many sources, making it available in a format that can be readily used for model evaluation (see the CCMI website).

For the proposed analyses to be successful we emphasize the need for the modelling teams to provide as much of the requested output as possible. In particular, several topics would benefit from high frequency output (daily or more frequent) of a few diagnostics, namely surface ozone and surface temperature. Detailed analysis of even more highly resolved model output (at every model time-step) has been proposed to explore OH, and will be requested for 4 consecutive days (July 1-4) for the years 1960, 1980, 2000 (most important), 2030, 2050, and 2100.

This high-frequency output is included in the CCMI-1 data request (see Breakout Group 1, above).

The three themes mentioned here are not intended to be exhaustive, and it is clear that the CCMI data set will represent an invaluable opportunity to explore many other climate-chemistry questions, be they related to the troposphere, stratosphere, or both. However, these topics provide an initial framework around which many members of the community can coalesce their efforts. Indeed, there are clear ideas for publications in place, and several opportunities for collaborations. An update on the analyses planned can be found on the CCMI website.

Breakout Group 3: CCMI support for 2015 WMO/UNEP Ozone Assessment

This group discussed the CCMI contribution to the upcoming 2014 WMO/UNEP Ozone Assessment, so as to ensure the most useful contribution possible within the constraints of the scientific community's ability to produce and analyse new simulations in the short timeframe available.

A major effort has been expended by the modelling community to produce simulations for both CCMVal-2 and CMIP5. These simulations have not yet been fully exploited and can be analysed in ways relevant to the new Ozone Assessment without having to wait for new model data. In particular, new research to connect model evaluation with uncertainties in model projections using CCMVal-2 data could be very useful, as this connection was not made in WMO (2011). At least a dozen modelling groups expected to complete the reference simulations for both the past and future by the end of 2013. Based on

past experience, this should provide sufficient time for results to be incorporated in the upcoming Ozone Assessment, as well as in papers being prepared for the assessment. Given that the number of simulations to be available by the end of 2013 is likely to be smaller than that provided by CCMVal-2 (especially with regards to fixed-GHG and fixed-ODS sensitivity simulations, which most groups will not likely be able to complete on this timescale), it seems that the best way forward is to use the existing simulations wherever possible, and use new simulations to update or extend results to fill specific gaps in knowledge or address particular uncertainties.

Differences between CCMVal-2, CMIP5, and CCMI simulations will need to be accounted for in the comparison of the different data sets. For GHGs, the reference simulations in CCMVal-2 used the SRES A1B GHG scenario, whereas CMIP5 and CCMI-1 use the Representative Concentration Pathways (RCPs). For ODSs, CMIP5 used the WMO (2007) A1 halogen scenario, whereas CCMVal-2 and CCMI-1 use the WMO (2011) scenario. Only a small subset of the CMIP5 models had interactive ozone (Eyring *et al.*, 2013b). For changes tied to surface warming (*e.g.* strengthened Brewer-Dobson Circulation (Butchart *et al.*, 2011; SPARC-CCMVal, 2010)), it should be relatively straightforward to relate the SRES A1B to RCP 6.0, which is the GHG scenario used in the CCMI REF-C2 simulation. For changes tied to chemistry, the models with interactive chemistry in CMIP5 should be sufficient to address (or at least bound) these effects, given that CMIP5 included a range of RCPs (Eyring *et al.*, 2013b).

It was recognized that RCP 8.5 is

considered “unrealistic” in terms of its methane scenario, but the group concluded that it would be unwise to try to define an alternative scenario. More generally, it was noted that the RCPs do not span parameter space for stratospheric applications, especially the chemical roles of N₂O and CH₄. However, trying to address this with additional CCMI sensitivity simulations was felt to be a “bridge too far” at this stage. Several single-model studies are addressing this issue.

Three particular topics might arise for the upcoming Ozone Assessment that will not be addressed by a large suite of the models participating in CCMI-1. The first topic is the sensitivity of ozone recovery to different GHG scenarios. Not many groups are committed to performing new GHG sensitivity simulations, so these sensitivities will likely be explored through studies by individual groups, and using the available CCMVal-2 and CMIP5 simulations (see above). Second, the SPARC Lifetimes Report includes revised halogen lifetimes and reaction rates. As a result, new ODS scenarios are being developed. At least three groups — WACCM, GEOSCCM, and SLIMCAT — are planning to explore the sensitivities to lifetimes and kinetics. More would certainly be welcome. The third topic is geoengineering. The consensus was that simulations to address geoengineering should be part of GeoMIP, and that sufficient published model studies exist for this topic to be assessed without an additional CCMI contribution.

Interactive chemistry is not necessarily critical for all topics, for example Arctic vortex variability, to be considered in Chapter 4 (the “climate” chapter of the upcoming Ozone Assessment). This chapter will likely draw heavily on CMIP5

results because of the use of coupled atmosphere-ocean models and the large number of simulations and ensembles available.

It was decided that the CCMVal-2 diagnostics were adequate for the purpose of the ozone assessment and that there was no need to add any more to the data request table. It was also agreed that it is too early to produce a coordinated CCMI report similar to SPARC-CCMVal (2010). Instead, several individuals volunteered to lead a particular CCMI multi-model analysis (see CCMI website for updates) that could be solicited by the chapters.

CCMI Scientific Steering Committee (SSC) Meeting

A CCMI SSC meeting was held following the main workshop. The SSC revisited the timeline and action items that were discussed throughout the workshop and identified individuals to move things forward (see above). It was decided to hold the next CCMI workshop, with a focus on the analysis of hind-cast simulations, in Lancaster, UK, from 20-22 May 2014. It was also agreed to push for diagnostics to be collected from the various people who analyse CCMI simulations within the ESMValTool. In addi-

tion, SPARC offered resources to be assigned to the development of the tool to ensure some of the key diagnostics for chemistry-climate analysis are integrated into the tool for improved model evaluation and benchmarking.

To help the overall coordination of CCMI, it was agreed that the CCMI SSC would elect a new co-chair through a formal process. The SSC meeting was followed by a nomination and voting period open to all CCMI SSC members. Michaela Hegglin (University of Reading, UK) was elected as new co-chair of CCMI, with Veronika Eyring (DLR, Germany) stepping down as CCMI co-chair at the end of 2013 when she started as chair of the CMIP Panel.

Acknowledgements

The workshop was held under the auspices of the International Global Atmospheric Chemistry (IGAC) Project, the WCRP's (World Climate Research Programme) SPARC (Stratosphere-troposphere Processes and their Role in Climate) project, and NCAR. We would like to thank NCAR and the University Corporation for Atmospheric Research (UCAR) as well as the local organising committee (Andrew Gettelman and Christy Edwards) for hosting the workshop.

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Workshop on Research Applications of High Resolution Radiosonde Data

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From 27-29 May 2013, 19 scientists from nine different countries took part in the Workshop on 'Research Applications of High Vertical Resolution Radiosonde Data (HVRRD)' at Stony Brook University, New York, USA. The meeting was sponsored by the US National Science Foundation, SPARC, and Stony Brook University. The objectives of the workshop were to provide a forum for research using HVRRD, to explore and encourage new applications of these data, and to explore the possibility of expanding the availability of international high vertical-resolution sounding data for use by the international research community.

The programme was comprised of a series of invited review papers on historical and current research topics, poster sessions, presentations on operational aspects of HVRRD, data availability, and access. Multiple discussion sessions were scheduled to cover topics arising from the presentations and directed discussions covering new research applications and improvements to data access.

Marvin Geller opened the meeting by outlining the background, motivation, and objectives of the workshop. He also introduced the first session, a series of invited review presentations on gravity wave and turbulence analysis using HVRRD.

Gravity Waves

A historical perspective on the use of HVRRD for the retrieval of gravity wave parameters was given by **Bob Vincent**. Observations of gravity waves in radiosonde soundings date back many decades. The development of empirical universal atmospheric gravity wave theory inspired the first use of HVRRD for a regional climatological gravity wave analysis. This work was one of the primary motivations for the original push to have operational radiosonde data archived at high resolution. **Ling Wang** provided an update on some recent gravity wave research using HVRRD, most of which has been conducted under the SPARC gravity wave activity, with focus on HVRRD from US upper air stations acquired from the US National Climate Data Center. Notable updates to analysis techniques include the retrieval of climatological high frequency gravity wave energy estimates from perturbations in the balloon ascent rate profiles. Other researchers have capitalised on the availability of the US HVRRD at the SPARC Data Center and carried out further gravity wave research, although their assumptions in isolating gravity wave temperature perturbations from background profiles have yet to be investigated and validated. Subsequent group discussions also noted that due care may not have been taken in the distinction between perturbations associated with gravity waves, turbulence, and

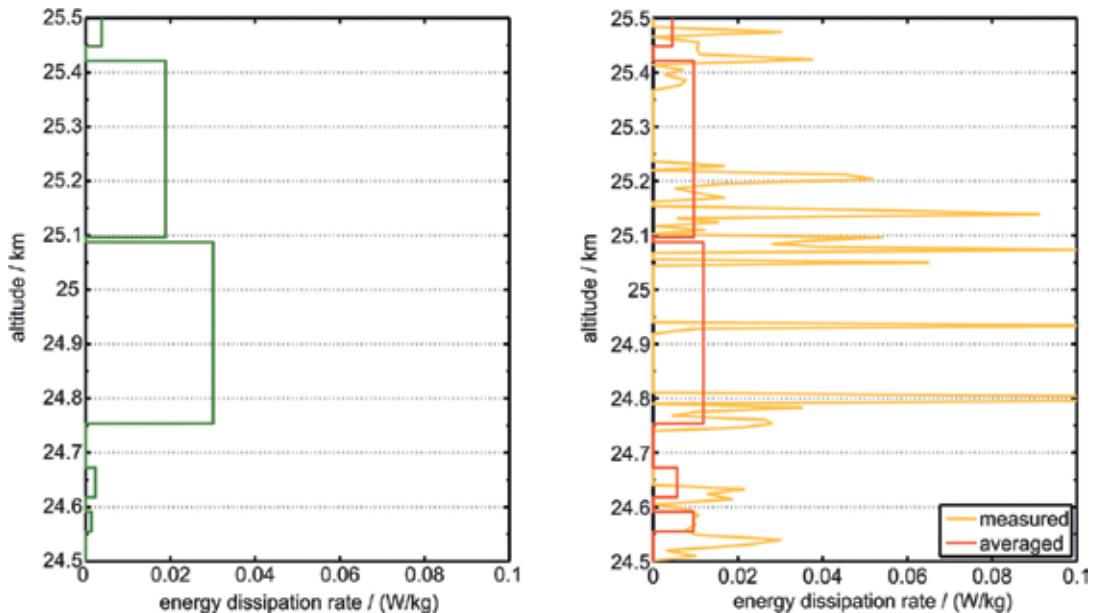
noise. The strong need for improved access to HVRRD was reaffirmed, citing the potential to obtain global distributions of gravity wave parameters to help constrain gravity wave drag parameterizations in GCMs.

Turbulence

Carol Anne Clayson provided an overview of turbulence parameter retrievals using the Thorpe analysis technique, first in oceanographic profiles and then in subsequent application of these methods to atmospheric soundings. This method infers regions of turbulence and characteristic scales of overturning, identifying regions of instability by comparing observed potential temperature profiles to reference profiles obtained by sorting the data points. **Nikolai Gavrilov** presented an alternative formulation of the Thorpe scale by which spectral parameters and turbulence characteristics were determined using stellar occultation scintillation measurements from GOMOS satellite photometers. Good agreement was found between these measurements and radar and radiosonde measurements from the MUTSI campaign. Correlations were found between the spatial distribution of turbulence and gravity waves.

In the poster session that followed, **Richard Wilson** addressed several important data quality issues in HVRRD Thorpe analyses.

Figure 6: Turbulent energy dissipation rates determined from high resolution pressure, temperature, and humidity sounding data using Thorpe analysis (left) and determined directly from constant current anemometer spectral analysis (right). (Figure courtesy Michael Gerding, Leibniz Institute of Atmospheric Physics).



Identification of spurious overturns caused by instrument noise can be mitigated by improving trend to noise ratios through smoothing and under-sampling. Further rejection of noise-induced overturns can be implemented with a comparison of the statistics of data range within an observed overturn with those of a noise sample of the same size. In regions of cloud the saturation of the air affects the stability, requiring the use of a moist-conservative potential temperature, although this is complicated by poor humidity sensor accuracy and slow response time at cold temperatures in the upper troposphere. Studies comparing typical operational radiosonde instrument retrievals with concurrent very high-resolution radiosonde, radar, and lidar observations have shown good agreement and have helped define the limitations of the various techniques.

All of these presentations highlighted the need for better estimates of proportionality between Ozmidov and Thorpe scales through further studies of concurrent radiosonde and other *in situ* and profiling radar and lidar observations. High-resolution

numerical simulations and statistical modelling were identified as other methods for improving the understanding of radiosonde response to turbulence.

The poster session included further presentations on turbulence. **Graeme Marlton** described the use of the PANDORA system, a magnetometer sensor package designed for operational use with Vaisala RS92 radiosondes. Evaluation of turbulence parameters from HVRRD formed part of a study by **Jie Gong** on gravity wave and turbulence impacts on thin tropopause cirrus clouds that are important for troposphere-stratosphere exchange of chemical species and water vapour. **Peter Love** demonstrated HVRRD Thorpe analysis of turbulence associated with gravity wave instability. A further invited presentation on turbulence was given in the afternoon session by **Michael Gerding**. He described the development of a constant temperature anemometer and thin wire resistance thermometer package for very high-resolution (<1mm) measurements. The instrument has been used to characterize turbulent layers in

the stratosphere, typically having depths of 30-50m. Comparisons of energy dissipation rates calculated directly from turbulence spectra with those determined by Thorpe analysis indicate that the latter technique may be over-estimating by a factor of around three, but that both agree qualitatively when comparable vertical averaging is applied to the spectral calculation (**Figure 6**).

GCOS Reference Upper Air Network (GRUAN)

In the final invited presentation of the first day **Holger Vömel** gave an overview of the Global Climate Observing System (GCOS) Reference Upper Air Network (GRUAN). He began the presentation by highlighting the inability to assess long-term trends in radiosonde observations of tropospheric water vapour due to unmanaged changes in instrumentation throughout data records. Other common quality issues in radiosonde data are traceability of measurements, including instrumental uncertainties and systematic errors, and incomplete metadata. GRUAN was established to address such issues in

response to the need of WMO and GCOS for the highest accuracy data possible. While the GRUAN data set currently only spans a few years and the network is still expanding, the standards and procedures set by GRUAN are pertinent to any research undertaken using HVRRD, even on very short records. The systematic and random uncertainties to which raw HVRRD are subject and the details of processing applied to produce derived data products are important considerations in any application of HVRRD.

Planetary Boundary Layer

Dian Siedel gave an invited presentation on the value of HVRRD in planetary boundary layer (PBL) studies. While the suitability of HVRRD for PBL studies varies depending on the parameters being measured, investigations into the dependence of PBL parameters on vertical sounding resolution have revealed dramatic improvements in the characterization of PBL heights and the frequency, depth, and intensity of surface based inversions as a result of increases in the resolution of operational radiosonde data (**Figure 7**).

Tropopause

Thomas Birner opened an invited presentation on tropopause research using HVRRD by discussing the history of the use of balloon techniques for atmospheric observations beginning in the second half of the 19th century, which then led to the discovery of the tropopause in 1902. Since then, HVRRD has continued to be one of the main observational tools used to investigate tropopause structure, with studies leading to the development of tropopause-based averaging for climatological characterization and the

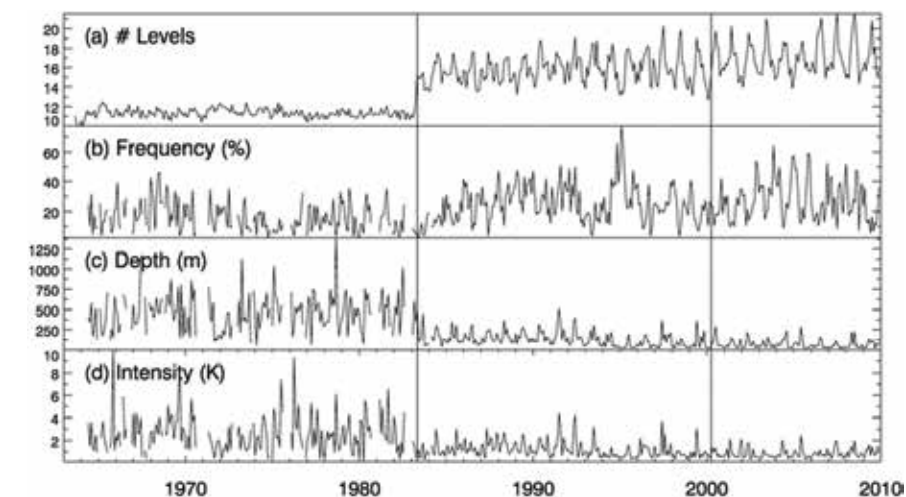


Figure 7: Surface based inversion characteristics derived from radiosonde observations at Jan Mayen, Norway, 1963-2009. The increase in sounding resolution in 1983 has a dramatic effect on the derived parameters. (Figure courtesy Dian Seidel, NOAA Air Resources Laboratory).

development of the concept of the tropopause inversion layer.

In the second poster session, **Yehui Zhang** presented a case study of the tropopause inversion layer at a mid-latitude US upper air station, noting the apparent relationship between the strength of the tropopause inversion layer and the maximum zonal wind and horizontal wind shear, as well as a correlation with lower stratospheric gravity wave activity. **Shu Meir Wang** investigated controls on the extra-tropical tropopause, including the role of baroclinic mixing in determining tropopause sharpness and whether resolving potential vorticity filamentation in GCMs is necessary to reproduce observed tropopause sharpness. **Wei Yuan** used decade-long averages of HVRRD to validate the representation of climatological tropical tropopause structure using standard resolution radiosonde data, so that multi-decade data sets could be applied to separate the Quasi-Biennial Oscillation from El Niño-Southern Oscillation signals in tropopause temperatures and altitudes.

Convection and Water Vapour in the Tropical Atmosphere

Juan Carlos Antuña Marrero gave an overview of investigations into water vapour variability and radiative transfer conducted in the Caribbean by the Grupo de Óptica Atmosférica de Camagüey and its predecessors. The group is planning to integrate HVRRD capabilities into their analysis suite. **Kusuma Rao** presented a detailed analysis of combined radiosonde and satellite observations over central India, the Bay of Bengal, and the Eastern Indian Ocean to determine the role of deep convection on tropopause structure and lower stratosphere temperature during the Indian summer monsoon.

Field Campaigns and Other Sounding Techniques

The National Center for Atmospheric Research Earth Observing Laboratory (EOL) instrumentation for field campaigns was described by **Junhong Wang**. The most requested facility, the GPS Advanced Upper Air Sounding

System, is a small, easily-operated, 1-second resolution radiosonde system that has been widely deployed for many successful campaigns. The EOL also operates a dropsonde capability, deployable from a variety of aircraft and driftsondes. Dropsondes offer similar observational capabilities to radiosondes for field campaigns, with the benefit of rapid deployment at opportunistically selected locations and times. Combinations of vertical and horizontal sounding techniques have proved highly successful in recent campaigns, for example, the Concordiasi field experiment in Antarctica.

Realizing the Full Potential of Operational Radiosonde Data

As discussed in the first session, the mid-1990s saw the emergence of various research applications of HVRRD, prompting a SPARC-led effort to advocate the archival of operational radiosonde data at native instrument resolution. While many countries have since adopted this practice, access to most of these data remains restricted, and other countries have yet to implement such practices. Improving access to HVRRD was therefore one of the main objectives of the workshop.

Workshop participants identified various aspects of existing radiosonde operations, data archival, and dissemination systems that are currently under-utilised. Most fundamentally, the process of recording and distributing operational radiosonde data on only mandatory and significant levels is a practice that was originally dictated by limited storage and communications capabilities, and motivated by only modest demands of limited computational capabilities. These decade-old technologies have long

since been superseded. Modern radiosonde systems are capable of recording operational data at native instrument resolution with rich metadata, resulting in volumes of data that are trivial in comparison to satellite observations and NWP/GCM (Numerical Weather Prediction/Global Climate Model) output. Similarly, the current WMO Global Telecommunications System (GTS) has the capacity to distribute radiosonde data at full resolution, a capability that is already being utilized by some radiosonde stations. Meanwhile, the demands of ever increasing NWP/GCM resolution need to be met with higher resolution assimilation data. It was therefore proposed that WMO guidelines be revised to standardize the recording and distribution of operational radiosonde data at high resolution.

High Vertical Resolution Sounding Data Archive

Large volumes of archived HVRRD currently exist in either centralized national repositories or distributed networks of individual station storage but largely remain difficult to access by most potential users. To realize the full potential of this existing valuable resource and to take advantage of a future GTS distribution of HVRRD, it was proposed that a global High Vertical Resolution Sounding Data (HVRSD) Archive be established. The vision for the archive would be to transition data collection and access from national meteorological organisations and PI-based research projects to long-term institutional data stewardship. By realizing a global database of HVRSD similar to the Integrated Global Radiosonde Archive, the HVRSD archive would facilitate observational studies of phenomena with vertical dimensions that span the scales

below those of standard radiosonde data resolution, including gravity waves, turbulence, tropopause, and planetary boundary layer processes. The archive would not be limited to operational radiosonde data and could include ship and campaign radiosonde data and other *in situ* sounding techniques such as dropsondes, ozonesondes, and super-pressure balloons.

SPARC Activity to Investigate Fine Scale Atmospheric Structures and Processes

HVRRD from US upper air stations have been made available from the SPARC Data Center, representing one of the few freely available repositories of HVRRD. While the data were originally acquired for research under the SPARC Gravity Wave Initiative (paid for by a US National Science Foundation grant), their availability has inspired a large and growing international community of data users developing a growing set of research applications well beyond the scope of their original application.

In anticipation of broader access to HVRSD, a new SPARC activity to improve understanding of fine-scale atmospheric structures and processes was proposed. One of the foremost activities would be to provide advocacy and guidance for the HVRSD Archive, promoting the data acquisition and their dissemination for the purpose of performing detailed process studies. The activity would identify and promote emerging research applications as well as the potential for regional and global studies and collaborations as access to HVRSD expands. Furthermore, it would advocate operational distribution of HVRRD. Potential deliverables proposed at the meeting included

a review article on new science emerging from the analysis of HVRSD; compilation of and access to climatological turbulence parameters; recommendations for establishment, refinement, or standardization of the definition and calculation of derived sounding parameters such as the tropopause; and a special journal issue. The benefits of the activity could also

extend to other WCRP projects with some interest already expressed from members of GEWEX.

Further information on the HVRSD Archive and proposed SPARC activity is available on the workshop website at www.sparc.sunysb.edu/workshop/. This site also provides access to selected presentations from the workshop and will be

updated as follow-on activities relating to the archive and activity progress. Currently, arrangements for the HVRSD Archive are being sought through the National Climate Data Center and a proposal for the SPARC project was prepared for the fifth SPARC General Assembly, held in Queenstown, New Zealand, in January 2014.



Report on the 7th Atmospheric Limb conference

16-19 June 2013 Bremen, Germany

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The seventh atmospheric limb conference was held from 16-19 June 2013 in Bremen, Germany. The conference provided a forum for experts to discuss scientific issues related to the use of satellite, airborne-, and balloon-borne limb measurements in the UV (ultraviolet)/visible, IR (infrared), and microwave spectral regions. These comprise current and future satellite limb-missions, algorithm development, as well as the interpretation of science results obtained for stratospheric and mesospheric minor constituents and aerosols, as well as their implications for atmospheric chemistry and physics.

The limb conference series was initiated in Bremen in 2003 with a workshop whose main focus was on satellite limb-scatter measurements. The following workshops and conferences in Stockholm (2004),

Montreal (2005), Virginia beach (2007), Helsinki (2009), and Kyoto (2011) were broadened in scope and attended by scientists representing limb observations not only in the UV/visible spectral range, but also in the IR and the microwave spectral regions. About 70 scientists attended the 2013 limb conference in Bremen (see **Figure 8**) and the program comprised 49 oral and 26 poster presentations. Due to travel restrictions, several participants were unable to attend the conference in person, but presented their results via Webex. The following subsections provide summaries of the results presented.

Recent and future space-borne limb missions

The conference commenced with an opening address by **John Burrows**, chairman of the conference organising committee. He began by

providing an overview of the results obtained from SCIAMACHY limb and occultation observations, and a discussion of the future needs for middle atmospheric remote sensing from space. **Kaley Walker** provided an overview of the ACE atmospheric mission comprising the ACE-FTS and MAESTRO instruments and data products. Recent results on the lifetime of ozone depleting substances (ODS), isotopic fractionation, and Arctic PSC (polar stratospheric cloud) measurements with the MAESTRO imagers were presented. In a follow-up presentation, **Chris Boone** discussed the current status of middle atmospheric profile retrievals from ACE-FTS in more detail, and presented first retrievals of PAN (peroxyacetyl nitrate) from ACE-FTS solar occultation observations (see **Figure 9**). PAN in the UTLS region shows a pronounced seasonal cycle,

qualitatively consistent with the seasonal cycle of biomass burning. **Yasuko Kasai** reported on the current status of SMILES/ISS data processing, presented selected science highlights, and discussed possible follow-up missions. **Takuki Sano** discussed several scientific applications of SMILES profile measurements including diurnal variations ozone abundances – even in the middle and lower stratosphere as well as total ozone columns (see **Figure 10**) – diurnal variations of ClO, HO₂, and HOCl, as well as ozone and ClO validation results. **Makoto Suzuki** discussed potential improvements of the SMILES instrument in the framework of a possible SMILES-2 mission.

Didier Rault presented initial exciting results from limb observations with the OMPS Limb Profiler onboard the Suomi-NPP spacecraft. Ozone and stratospheric aerosol profile retrievals show very



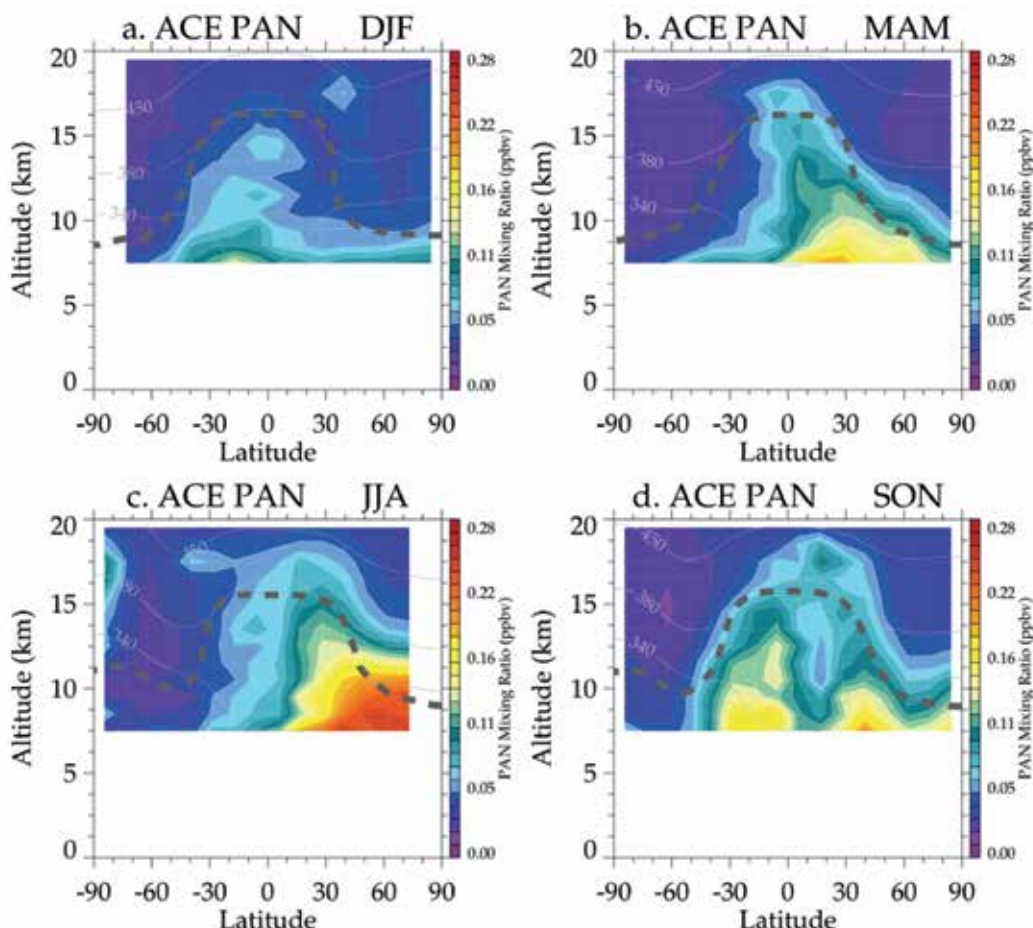
Figure 8: Participants of the seventh international limb conference.

good agreement with independent observations. A highlight of the presentation was the observation of an aerosol plume associated with the February 2013 Chelyabinsk meteor that could be tracked with OMPS-LP aerosol retrievals for many weeks after the event occurred (see **Figure 11**). In the following presentation, **Doug Degenstein** provided an overview of the science achievements based on OSIRIS limb-scatter observations from the past 12 years. The focus of the

presentation was on the OSIRIS stratospheric ozone profile data product, which is of high quality.

Erkki Kyrölä provided an overview of the GOMOS instrument, retrievals, and the available data products including vertical profiles of O₃, NO₂, NO₃, OClO, stratospheric aerosols, and noctilucent clouds (NLCs). The observations include stellar occultation measurements taken on Earth's night-side and limb-

Figure 9: Zonal mean distributions of seasonal average PAN (peroxyacetyl nitrate) mixing ratio in the UT/LS region. The white solid lines correspond to potential temperature contours, and the grey dashed line shows the average thermal tropopause. Figure from Tereszchuk *et al.*, 2013.



scatter observations on the day-side. **Didier Fussen** presented the ALTIUS (Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere) concept, a 2-D UV/visible/NIR (near-infrared) limb-imaging instrument with acousto-optical tunable filters (AOTF) for wavelength selection. ALTIUS will perform multi-mode observations in limb-scatter, occultation (solar, stellar, and lunar) as well as nadir geometry, proving vertical profiles of O₃, NO₂, and stratospheric aerosols, amongst other atmospheric species and parameters. ALTIUS was also the topic of **Emmanuel Dekemper's** poster presentation, which showed the first measurements made with a ground-based AOTF spectrometer. **Glen Jaross** provided an overview of the OMPS Limb Profiler instrument (onboard the Suomi/NPP satellite) and reported on the current status of the sensor performance, discussing instrument monitoring and calibration aspects. This presentation was complemented by **Pawan Bhartia's** talk focusing on the ability to model the observed limb radiance profiles as well as tangent height registration with the Rayleigh Scattering Attitude Sensor method. **Marty McHugh** provided an overview of the Doppler Wind and Temperature Sounder, a novel instrumental concept to measure wind and temperature profiles from the stratosphere up to well within the thermosphere, during both day and night. The measurements are based on a gas filter correlation radiometer imaging the limb emissions of NO and CO₂. The session on recent and future missions was completed by **Thomas Piekutowski's** overview of the Chemical and Aerosol Sounding Satellite, a Canadian mission concept including next-generation instruments based on ACE-FTS and OSIRIS.

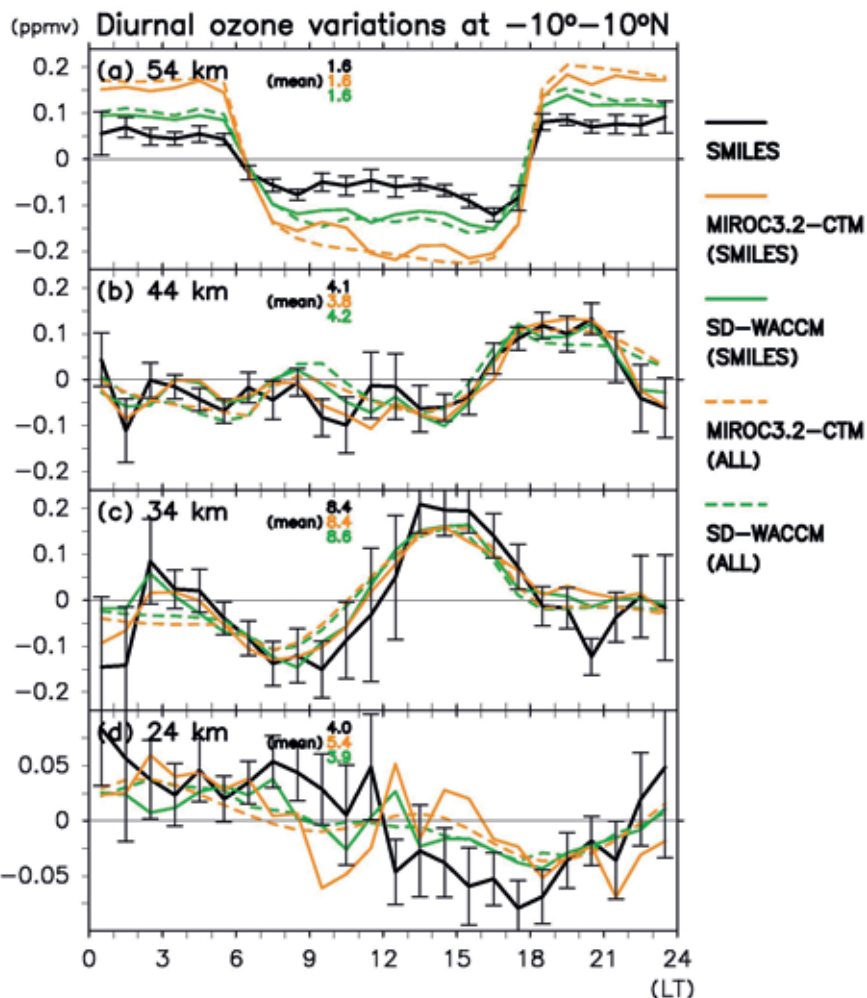


Figure 10: Diurnal variation of ozone averaged from 10°S – 10°N at (a) 54km, (b) 44km, (c) 34km, and (d) 24km altitude. SMILES measurements are shown as black solid lines. Orange and green solid curves show model results based on MIROC3.2-CTM and SD-WACCM, respectively, sampled at the locations and times of SMILES observations. The dashed orange and green lines show the full-grid results of these two models. The daily-mean values for SMILES, MIROC3.2-CTM and SD-WACCM are shown as figures with the same colour coding as the lines. Figure adapted from Sakazaki *et al.*, 2013.

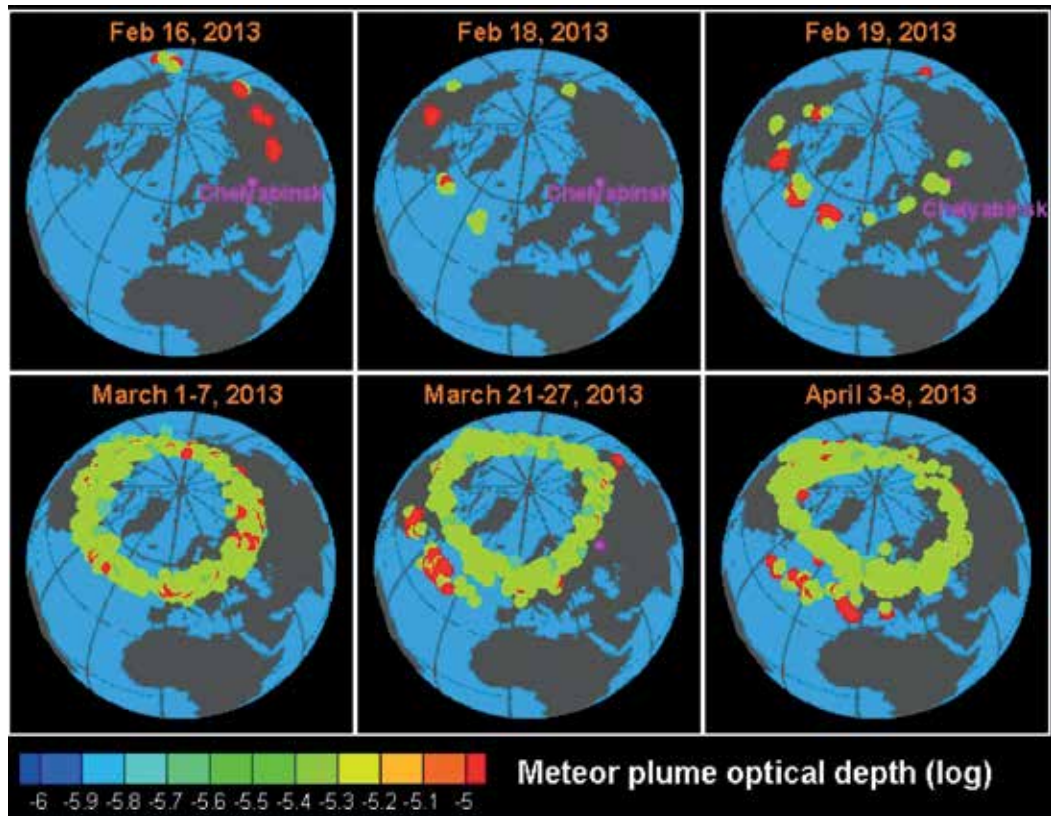
Stratospheric trace gases, climatologies, and trends

The stratospheric trace gas session was opened with a presentation by **Janis Pukite**, who employed SCIAMACHY retrievals of stratospheric NO₂ profiles to study transport barriers, identified by maximum gradients in NO₂, in the tropics and near the polar vortex. The transport barrier latitudes exhibit characteristic seasonal and Quasi-Biennial Oscillation (QBO) signatures and show good agreement with simulations from the EMAC model. **René Hommel**

reported on the determination of total inorganic bromine (Br_y) species from SCIAMACHY measurements of stratospheric BrO profiles using modelled ratios of Br_y and BrO. The Br_y budget is still uncertain and the contributions of different sources, particularly of very short lived species (VSLs) to the stratospheric Br_y budget are not well understood.

Gabriele Stiller reported on stratospheric CFC-11 and CFC-12 profile measurements made with MIPAS (onboard Envisat). While the CFC trends are negative in the upper troposphere/lower

Figure 11: OMPS-LP retrievals of the optical depth of the Chelyabinsk meteor dust plume from February 16, 2013, *i.e.*, one day after the asteroid entered the Earth's atmosphere, until early April 2013. The plume was detected in the OMPS-LP stratospheric aerosol profile retrieval, and occurred at altitudes well above the Junge layer. By February 19, the plume had completely circled the Earth at mid-northern latitudes (Figure courtesy Didier Rault). More information on OMPS-LP observations of the Chelyabinsk dust plume can be found in Gorkavyi *et al.*, 2013.



stratosphere (UTLS) region, positive trends are observed at higher altitudes, which cannot be explained considering the age of air (see **Figure 12**). These unexpected positive trends may be indicative of changes in the Brewer-Dobson-Circulation. **Maryam Khosravi** presented a NO_x climatology based on measurements from the two instruments on the Odin satellite, using OSIRIS NO_2 and SMR NO profile retrievals. **Susann Tegtmeier** provided an overview of the current status of the SPARC data initiative, a comprehensive activity to provide climatologies of all relevant minor species for model verification and validation. The O_3 and H_2O chapters of the final report are finished, and the chapters for most other species are well underway. **Kazutoshi Sagi** reported on chemical ozone loss in the Arctic polar vortex derived from Odin/SMR ozone profile observations using the DIAMOND assimilation system. Chemical ozone losses during the unusual winter/

spring of 2010/2011 were found to be more severe than in 2004/2005 in the 450-550K isentrope range, in agreement with other studies. The following two talks focused

on the determination of trends in stratospheric ozone based on different satellite data sets. **Erkki Kyrölä** used ozone profile measurements with SAGE-

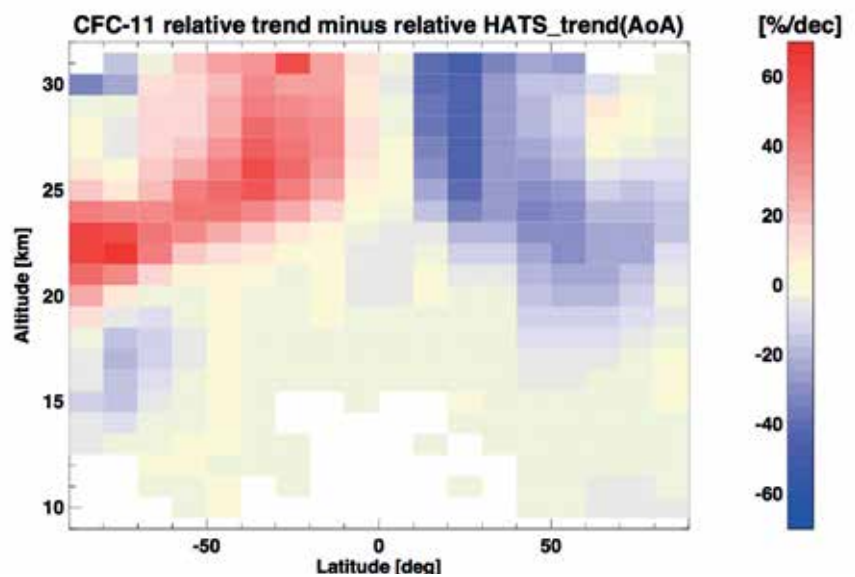


Figure 12: Latitude and height dependence of the relative trend (in %/decade) in MIPAS CFC-11 measurements corrected for CFC-11 surface trends and considering the age of air at each particular latitude and height. The remaining and unexplained trends may be indicative of changes in transport and mixing patterns, *e.g.*, changes in the Brewer-Dobson circulation. Figure from Kellmann *et al.*, 2012.

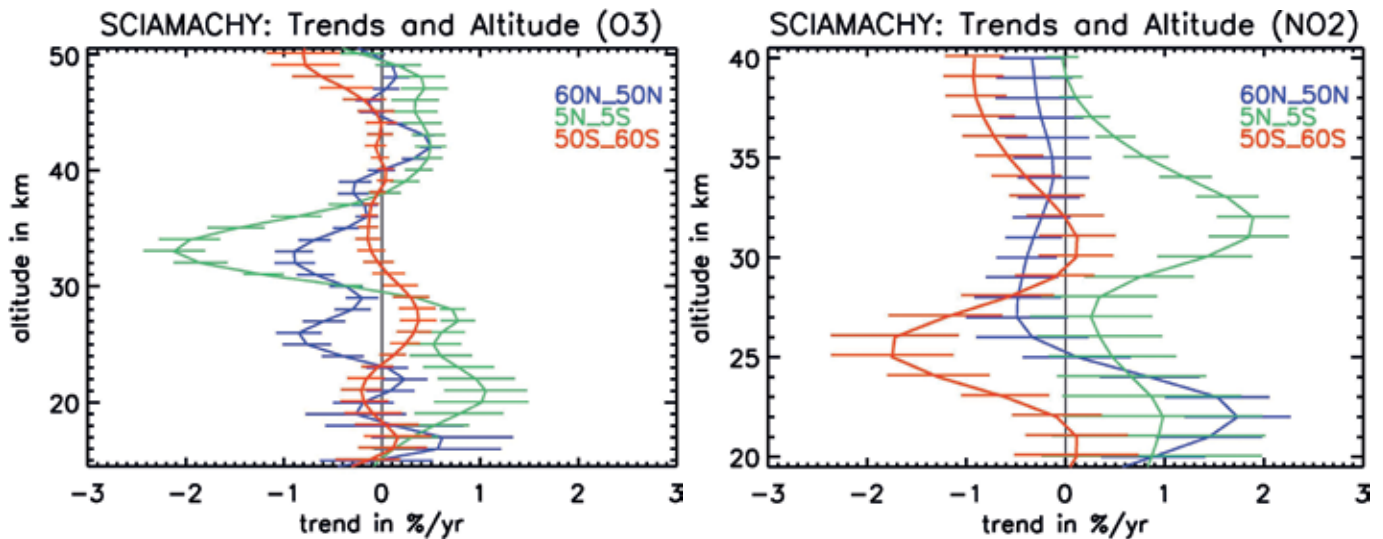


Figure 13: Left panel: Altitude profiles of O₃ trends for 60°–50°N, 5°N–5°S, and 50°–60°S, derived from SCIAMACHY limb-scatter measurements. In the tropics, both positive trends between 15–30km and negative trends between 30–35km are seen by SCIAMACHY. Moderate positive trends in the 40–50km altitude range at northern mid-latitudes and in the tropics are expected due to the decline in stratospheric halogen load. Right panel: As for left panel, but for NO₂ – also retrieved from SCIAMACHY limb-scatter observations. For latitudes of 5°N–5°S and altitudes of 30–35km, O₃ and NO₂ show trends with similar absolute values, but of opposite sign. This likely reflects a connection between O₃ and NO_x chemistry. At mid-latitudes an asymmetry is observed between 20–30 km with positive/negative trends for 60°–50°N/50°–60°S. Figure taken from Gebhardt *et al.*, 2013.

II, GOMOS, and OSIRIS to study long-term variations in stratospheric ozone over the last three decades. The turn-around in upper stratospheric ozone trends was found to occur in the late 1990s, in agreement with earlier studies. In the tropical middle stratosphere, at around 30km altitude, strong negative trends of -5 to -7%/decade were identified, even in the last decade. This finding was also confirmed by the results presented by **Claus Gebhard**, who reported on decadal trends of stratospheric O₃ and NO₂ seen in SCIAMACHY observations. The negative O₃ trend in the tropical middle stratospheric ‘island’ coincides with a positive trend in NO₂ in the same latitude-altitude region (see **Figure 13**) and is also seen in OSIRIS and MLS stratospheric ozone measurements. **Jo Urban** provided an update of the SMR/Odin measurements of H₂O and H₂O isotopologues. The time series shows clear evidence of the unusual drop in H₂O mixing ratio around 2001,

coinciding with a decrease in TTL minimum temperature. Moreover, first indications of a new sudden decrease in late 2012/early 2013 are also present in the SMR H₂O data set. **Stefan Lossow** investigated the long-term variation of stratospheric H₂O based on HALOE and MIPAS data sets. A cumulative sum method was used to determine break-points in the H₂O time series. **Gabriele Stiller** provided an overview of the SPARC WAVAS-II H₂O satellite data quality assessment, and showed selected results of stratospheric H₂O, including comparisons between the different satellite data sets that are available. **Farahnaz Khosravi** discussed the sensitivity of polar stratospheric cloud (PSC) formation and PSC duration to changes in temperature and the abundance of stratospheric H₂O. The results show that PSCs react sensitively to small changes in these parameters, implying that stratospheric climate change will affect PSCs.

Klaus Bramstedt reported on precise tangent height retrievals from SCIAMACHY solar occultation measurements, which yield tangent height uncertainties on the order of a few tens of meters for individual measurements. Moreover, a novel H₂O profile data product based on a DOAS approach was presented. **Stefan Noël** presented updated results of stratospheric CH₄ and CO₂ profile retrievals, also from SCIAMACHY solar occultation measurements. The 10-year CH₄ time series shows no obvious trend in the stratosphere, but CO₂ was found to increase by about 0.5%/year, in good agreement with Carbon Tracker model results. The stratosphere session was completed with **Matthew Toohey**’s presentation on uncertainties in monthly mean trace-gas climatologies caused by specific temporal-latitudinal sampling patterns associated with different satellite instruments. Particularly for non-uniform sampling (*e.g.* by occultation measurements) the

sampling-related uncertainties in monthly mean climatologies are not negligible. The study further showed that the standard error of the mean estimator is generally a conservative estimate of the random error in zonal and monthly mean data sets.

The majority of the posters presented at the conference dealt with stratospheric applications and processes. In her poster presentation **Katja Weigel** showed results of the latest version of the UTLS H₂O profile retrieval from SCIAMACHY limb-scatter observations. **Jian Xu**'s poster dealt with the retrieval of stratospheric minor constituent profiles from TELIS balloon observations. Tropospheric ozone column retrievals from SCIAMACHY measurements of total ozone columns and stratospheric ozone profiles were presented in the poster by **Felix Ebojie**. Several poster presentations dealt with the scientific analysis and interpretation of measurements and/or model simulations of stratospheric species. **Sven Köhl** compared satellite measurements of OCIO to EMAC simulations. SMILES and ACE-FTS measurements of stratospheric species were used by **Naoko Saitoh** to study processes in the Arctic polar stratosphere. Results of a potential ozone mini-hole during the 2010/2011 Arctic winter were presented by **René Hommel**. Some of the posters related to the stratosphere focused on the validation of MIPAS (**Alexandra Laeng**), SMILES (**Takuki Sano**), SCIAMACHY O₃ (**Jia Jia**, **Nabiz Rapoe**), NO₂ (**Ralf Bauer**), and BrO (**Faiza Azam**) data products. The poster by Hideo Sagawa provided an overview of the current status of SMILES Level-2 Processing at NICT. SMILES measurements of ClO, HO₂, HOCl, and BrO were the focus of **Makoto Suzuki**'s poster.

Stratospheric aerosols

The session started with **Adam Bourassa**'s update of stratospheric aerosol extinction profile retrievals from OSIRIS/Odin limb scatter observations. The latest version of the retrieval also includes limb-radiances measured by OSIRIS's 1530nm IR channel, in addition to limb measurements by the optical spectrograph. **Filip Vanhellemont** reported on improvements of stratospheric aerosol retrievals from GOMOS stellar occultation observations with the AERGOM algorithm. Data filtering by rejecting measurements with cold and weak stars were convincingly demonstrated to further improve agreement of GOMOS extinction profile retrievals with SAGE-II solar occultation measurements. **Christine Bingen** provided an overview of the stratospheric aerosol activities within ESA's aerosol CCI project. The focus of the stratospheric part of the CCI is on stratospheric aerosol retrievals from GOMOS stellar occultation observations, but possibilities to combine the GOMOS and SAGE-II stratospheric aerosol records will be investigated as well. **Lena Brinkhoff** reported on the global morphology of stratospheric aerosol extinction based on the SCIAMACHY limb-scatter retrievals of stratospheric aerosols. Signatures of several volcanic eruptions, as well as characteristic seasonal and QBO-variations are clearly visible in stratospheric aerosol extinction. The SCIAMACHY limb-scatter measurements were also the basis of the stratospheric aerosol retrievals discussed by **Steffen Dörner**. Aerosol extinction profiles are retrieved at a single wavelength using an onion peeling approach and the McArtim radiative transfer model. One focus of

this study was on the effects of spatial inhomogeneities in aerosol extinction. A novel balloon-borne limb imaging instrument called ALI (Aerosol Limb Imager) was presented by **Brenden Elash**. ALI, comprising an AOTS (Acousto-Optical Tunable Spectrometer) will provide spectral limb images with high vertical and horizontal resolution, and is scheduled for launch on a stratospheric balloon in summer 2014. **Aldona Wiacek** described a comprehensive modeling investigation to determine the sensitivity of limb radiance profiles at several UV, visible, and NIR wavelengths to absorbing aerosols, as well as to sulfate and ice particles. In addition, the poster presented by **Florian Ernst** was devoted to stratospheric aerosol profile retrievals from SCIAMACHY limb-scatter observations.

Mesosphere and lower thermosphere

Several presentations reported on retrievals of minor constituents, background atmospheric parameters, and aerosols in the mesosphere and lower thermosphere. **Christian von Savigny** presented recent results of 27-day and 11-year solar cycle signatures in SCIAMACHY OH rotational temperatures near the mesopause. A solar-driven 27-day signature was clearly identified and the quantitative sensitivities of temperature to changes in solar forcing at the 27-day and 11-year time scale were found to agree within uncertainties, suggesting that similar physical/chemical mechanisms drive the temperature response to solar forcing. **Stefan Bender** reported on NO profile retrievals in the mesosphere/lower thermosphere (MLT) region using SCIAMACHY observations of non-resonant NO transitions in the UV airglow. The retrievals are in

good agreement with MIPAS NO measurements and show evidence for downwelling of NO-rich air masses in spring 2009, after the occurrence of the unexpected major sudden stratospheric warming (SSW). Mg and Mg+ concentration profiles in the MLT region retrieved from SCIAMACHY airglow observations in the UV-B spectral range were reported by **Martin Langowski**. The Mg+ concentration peak occurs about 10km above the Mg peak and both species showed characteristic seasonal and latitudinal patterns. In her presentation, **Kristell Pérot** discussed effects of energetic particle precipitation (EPP) as well as SSW on middle atmospheric NO abundances observed with SMR on Odin. **Ole Martin Christensen** presented first retrievals of H₂O profiles near the polar summer mesopause in the vicinity of NLCs/ polar mesospheric clouds (PMCs) based on a special MLT mode of SMR/Odin. The retrievals allow an improved vertical resolution of the H₂O profiles compared to nominal mode observations and clearly show evidence for the 'freeze-drying' effect around NLCs. **Marty McHugh** provided an overview of the latest research on PMCs using the SOFIE instrument on the AIM satellite. Highlights included direct observations of meteoric smoke extinction and recent results of middle atmospheric CO₂ trends of about +2ppmv/year. **Oleg Ugolnikov** reported on upper mesospheric temperature profile retrievals based on ground-based Rayleigh twilight polarization measurements from an observatory near Moscow. The retrieved temperature profiles were shown to be in good agreement with TIMED/SABER and Aura/MLS satellite observations. The following two presentations were based on middle atmospheric species observations

with the SMILES instrument. First, **Kota Kuribayashi** employed SMILES measurements of ClO and HOCl in the lower mesosphere to empirically determine the rate constant of the reaction $\text{ClO} + \text{HO}_2 \rightarrow \text{HOCl} + \text{O}_2$. The middle and upper atmospheric session was concluded by **Kengo Yokoyama's** talk, who presented SMILES retrievals of middle atmospheric HCl profiles, which were shown to be in very good agreement with independent measurements below an altitude of 45km. Possible reasons for discrepancies with other measurements in the mesosphere were discussed. First results of atomic oxygen profile retrievals in the MLT region from SCIAMACHY oxygen green line nightglow measurements were presented in **Olexandr Lednyts'kyi's** poster.

Airborne limb measurements

The four oral presentations in this session described airborne measurements using a variety of instruments and spectral ranges. **Tobias Guggenmoser** presented first results of retrievals from GLORIA-AB measurements performed during the TACTS/ESMVal field campaigns in 2012, including the first 3D tomographic retrievals. In a related poster presentation, more details of the 3D trace gas retrievals were presented by **Jörg Blank**. In the following presentation, **Christoph Kalicinsky** reported on O₃, ClONO₂, and CFC-11 fields retrieved from CRISTA-NF measurements during the RECONCILE campaign in early 2010. Vortex dynamics and filamentary structures are well observed with these measurements, in very good general agreement with CLAMS model simulations. **Bodo Werner** presented first results of UV/Vis/NIR DOAS measurements obtained during field campaigns

with NASA's Global Hawk unmanned aerial vehicle, which allows continuous measurements in the UTLS for periods of 24 hours or more. In the last oral presentation of the conference, **Jörn Ungermann** reported on CRISTA-NF observations of fine filamentary structures in different minor constituents with vertical extensions of partly less than 1km. Interestingly, these small-scale structures were traced back to a breaking Rossby wave using trajectory analysis.

Radiative Transfer Model (RTM) Development

Several poster presentations were dedicated to the development and improvement of RTMs. **Robert Loughman** presented a poster on limb scattering RTM development in support of the OMPS Limb Profiler Mission. A Monte Carlo RTM for limb-scattered sunlight measurements was presented by **Chris Roth**. **Vladimir Rozanov** reported on new developments in terms of modeling rotational Raman scattering in limb-viewing geometry using the SCIATRAN RTM. **Tatyana Klimeshina's** poster dealt with calculations of the H₂O continuum absorption spectrum in two IR spectral windows, which showed good agreement with experimental results.

General and concluding remarks

A critical issue emphasized in many presentations and discussions was the urgent need for follow-up satellite limb instruments providing vertical profile information with high vertical resolution and global coverage. With the loss or shutdown of SAGE-II, SAGE-III, and HALOE between October 2005 and April 2006, as well as the sudden loss of Envisat in April 2012, the

number of atmospheric remote sensing instruments with limb profiling capability has decreased significantly.

A novelty of this limb conference was the student paper awards for the best oral and poster presentations. The award for the best student oral presentation went to **Bodo Werner** (Institute of Environmental Physics, University of Heidelberg) for his talk entitled “*UV/vis/near-IR limb measurements onboard the NASA Global Hawk in the tropical tropopause layer (TTL)*”, and **Florian Ernst** (Institute of Environmental Physics, Bremen University) received the best poster award for his poster on “*Global stratospheric aerosol extinction profile retrievals from SCIAMACHY limb radiance: algorithm description and validation*”.

It was decided to organise a joint AMT/ACP (Atmospheric Measurement Techniques/Atmospheric Chemistry

and Physics) special issue on all aspects regarding limb measurements and scientific exploitation of the retrieved data. This special issue is already open for submissions. Guest editors are Stefan Bühler, Farahnaz Khosravi, Erkki Kyrölä, Patricia Liebing, Gabriele Stiller, and Christian von Savigny. The next limb conference is scheduled to take place at Chalmers technical University in Gothenborg, Sweden, in June 2015.

Last, but not least, the conference organising committee and the recipients are very grateful for the travel support kindly provided by SPARC.

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Report on the Atmospheric Composition and the summer Asian Monsoon (ACAM) Workshop

9-12 June 2012, Kathmandu, Nepal

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120 scientists representing 17 countries gathered in Kathmandu, Nepal, for the Workshop on Atmospheric Composition and the Asian Summer Monsoon (ACAM). As a weather pattern, the Asian monsoon impacts the lives of more than a billion people. With rapid population and economic growth of countries within the region over the past decade, interaction between increasing surface emissions and monsoon convection plays an important role in the region's air quality. The uplift of pollutants also enhances aerosol-cloud interactions that may change the behaviour of the monsoon. The chemical transport effect of the monsoon system is seen from satellites as an effective transport path of pollutants into the stratosphere. The monsoon system is therefore relevant to scales and processes bridging regional air quality, climate change, and global chemistry-climate interactions. Accurate representation of this system in global chemistry-climate models is critical to predicting how this evolving region may contribute to future change. To characterize and quantify the impact of the system, integrated study is essential, including observations (*in situ* and remote sensing) from the surface through the troposphere and

stratosphere as well as modelling from regional to global scales. To be successful in this pursuit, it is necessary to build strong international collaborations to obtain the diverse expertise, resources, and access to the monsoon region for international research teams. The ACAM workshop represents a small but critical step in building these international relationships. Recognizing the importance of this problem, SPARC was joined by four other organizations as co-sponsors of the 3.5 day workshop. Co-sponsors were IGAC, iLEAPS, ICIMOD, and the US National Science Foundation.

The workshop began with three overview presentations providing

a perspective of the importance of the Asian monsoon system to global climate and related chemical impacts. Dynamics and predictability of the Asian monsoon system were addressed by **Madharan Rajeevan** who emphasized the need to address variability across multiple scales including diurnal, intraseasonal, interannual, decadal, and longer. Understanding of these timescales is fundamental to isolating effects related to atmospheric composition in this meteorologically complex environment.

An overview of current understanding of chemical impacts of the Asian summer monsoon anticyclone in the upper troposphere/lower

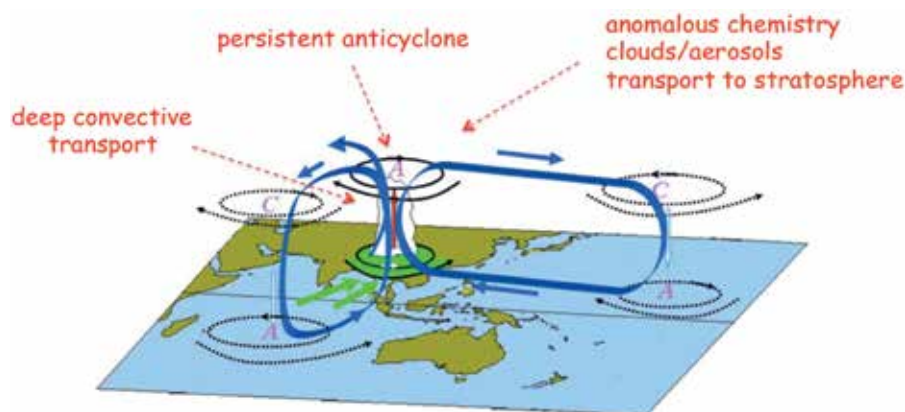


Figure 14: Large-scale summer circulation demonstrating the transport pathways from the surface to the upper atmosphere. Figure courtesy Bill Randel, NCAR.

stratosphere (UTLS) was provided by **Bill Randel (Figure 14)**. Strong evidence for the global significance of this region was presented based on satellite observations indicating enhanced concentrations of pollutants in the stratosphere. Supporting dynamical analysis and modelling demonstrate how these perturbations result from convective transport in the monsoon anticyclone region. *In situ* verification is the major gap limiting more complete understanding and quantification of these impacts.

Mark Lawrence provided a much needed historical perspective on southern Asian pollution outflow, highlighting previous efforts to understand emissions and transport in the near-field lower atmosphere during INDOEX and other studies, as well as in the upper atmosphere downwind of the region during MINOS and other studies. These studies represent our best information to date on the interplay between emissions and transport, and provide a critical baseline for comparison in a region that continues to experience rapid change.

The body of the workshop was organized around four themes, each representing a key aspect of the connection between atmospheric composition and Asian monsoon dynamics. For each session, conveners prepared summaries that are provided below. In addition to these oral sessions, poster sessions provided additional time for participants to share their work and get acquainted.

Session 1.
Emissions and Air Quality
(Hiroshi Tanimoto and Mark Lawrence)

The session started with four invited talks (**Greg Carmichael, Jun-**

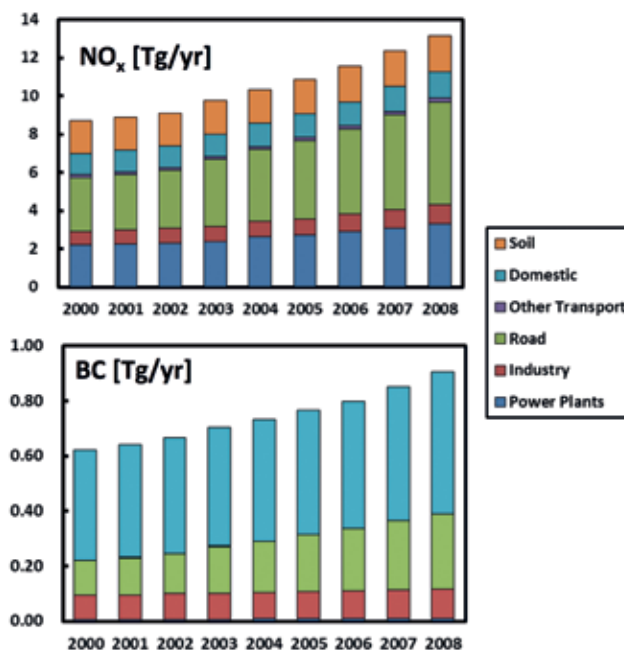


Figure 15: Example of increasing emissions in South Asia from the Regional Emissions Inventory in Asia (REAS) version 2.1 (Kurokawa *et al.*, 2013). Growth in road emissions is becoming a dominant source of NO₂ and increasingly contributes to black carbon, which continues to be dominated by domestic use of biofuels. Figure courtesy Jun-ichi Kurokawa, Asia Center for Air Pollution Research.

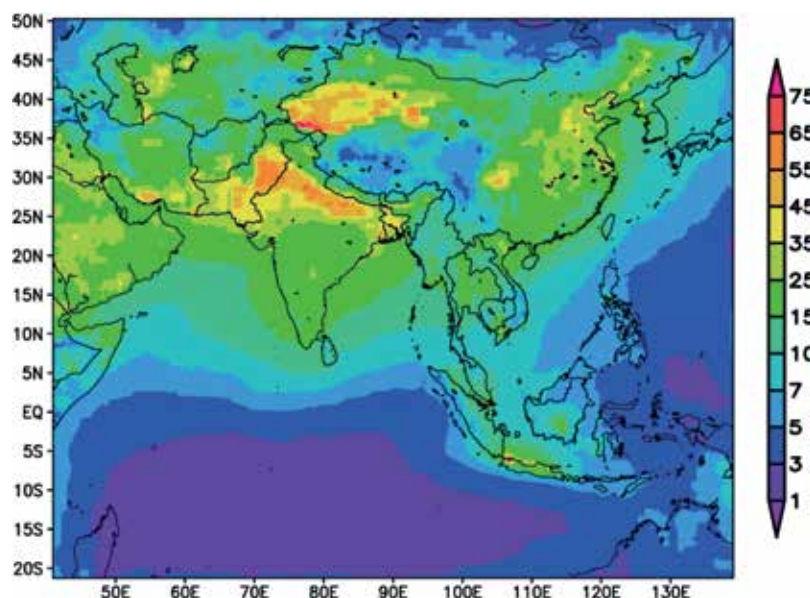


Figure 16: Four-year mean surface PM_{2.5} concentrations in Asia based on a regional model with assimilation of MODIS AOD (Carmichael *et al.*, 2009). PM_{2.5} concentrations are high throughout monsoon Asia, with contributions from dust, biomass burning and anthropogenic activities. Concentrations and composition vary by season and regions. Figure courtesy Greg Carmichael, University of Iowa.

ichi Kurokawa, Vinayak Sinha, Xuemei Wang), followed by nine contributed talks (**Maheswar Rupakheti, Bhupesh Adhikary, Elisa Vuillermoz, Patrick Ginot, Shichang Kang, Jason Cohen, Chinmay Jena, Eri Saikawa, Hongyu Liu**). The talks focused on two major topics: emissions and air quality.

The emission sources that are most significant for Asia were noted: brick kilns, garbage burning, agriculture burning (wheat, rice paddies), and vehicles, especially diesel trucks and buses. Highlights included:

- A large uncertainty in the important regional emissions of volatile organic compounds (VOCs) from biomass burning

and biogenic sources;

- An increase in emissions of particulate matter from road transport, due to increasing motorization (**Figure 15**)
- Evidence of a decrease in emissions from the residential sector in Tibet
- Implementation of multi-pollutant emission control in large cities in China
- Completion and availability of a new emission inventory for Asia (REAS-v2), and a comparison between emission inventories is currently being undertaken as part of the MICS-Asia activity.

Air quality issues were also discussed (**Figure 16**). One of the main highlights, being in Kathmandu, was the SusKat-ABC campaign, which has the goal of better understanding the sources and mechanisms of chemical production and loss for air pollution in the Kathmandu Valley, greater Nepal, and northern Indian areas, particularly in support of developing strategies for the engagement of stakeholders towards the implementation of mitigation strategies for air quality in this region. Associated, ongoing field observations are being made at several sites, including one in Kathmandu (Pakanajol) and the Nepal Climate Observatory-Pyramid (NCO-P). From these observations it was found that current chemistry transport models significantly overestimate BC concentrations in the wet seasons.

Other highlights included:

- It was found that not only BC, but also dust plays an important role in the impact on glaciers
- South Asia was found to be a hotspot for surface ozone due to high emissions of ozone precursors and high levels of

solar radiation

- The impact of indoor air quality on human health was highlighted.

In the discussion session, it was suggested that more collaboration among atmospheric, cryospheric, and hydrological scientists is needed to better understand the emissions and transformation of air pollutants and the resulting impacts on the regional climate and hydrological cycle. Links of emissions to air quality can be strengthened by sharing information about emissions data and model setups, identifying key sources (including agriculture), identifying key compounds (including NH_4), and differentiation of emission factors. Links of observations of all types (including archives like ice cores and old data) to each other and to modelling, including cross-improvements, would be valuable. Links from air quality to impacts on health, agriculture, snow and glaciers, visibility/tourism, and two-way links to climate change are also important. The connection between surface emissions and air quality on the one hand and the UTLS Asian Monsoon outflow and stratospheric composition on

the other hand should be made. Finally, collaboration is needed on linking studies of air quality and mitigation options to policy needs and opportunities.

Session 2: Aerosols and Clouds (Arnico Panday and S. Suresh Babu)

The session began with an invited talk by **Suresh Babu** on 'Trends in Aerosol Optical Depth over the Indian region: Potential causes and Impacts'. His overview highlighted the results from long-term observations as well as campaigns over the Indian region looking at aerosol and their radiative effects (**Figure 17**). This includes: (1) trends in aerosol optical depth (AOD) over India based on long-term observations from a network of aerosol observatories, now known as the Aerosol Radiative Forcing over India Network (ARFINET); (2) three dimensional distributions of aerosols and their heating rates over the Indian region combining ground-based data from network and oceanic cruise measurements with aircraft measurements conducted as part of the Integrated Campaign on Aerosols gases

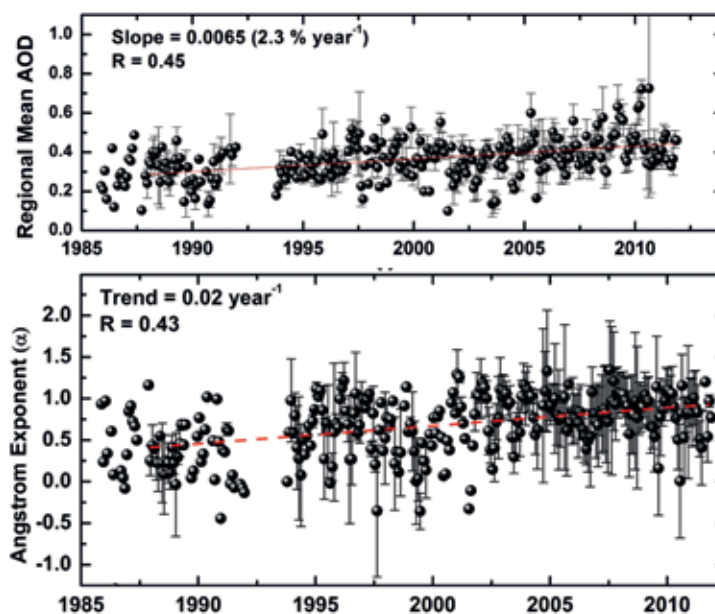


Figure 17: Increasing trends in aerosol optical depth and angstrom exponent across the ARFINET sites demonstrate the role of anthropogenic influence. Figure from S. Suresh Babu *et al.*, 2013.

and Radiation Budget (ICARB); (3) elevated layers of BC over the Indian region and associated heating at free tropospheric altitudes measured using high altitude balloon flights; (4) aerosol-cryosphere interactions over the Himalayan region; and, (5) future campaigns planned over the Indian region as a part of the Regional Aerosol Warming Experiment (RAWEX), which will employ aircraft, high altitude balloons, and long term observations from high altitude stations over the Himalayas in addition to ARFINET. **Susanne Bauer** made a presentation on historic and future black carbon deposition over India, while **Ritesh Gautam** made a presentation on satellite observations of Himalayan snow darkening induced by desert dust. **Chiara Cagnazzo** presented coupled aerosol-climate model simulations of the impact of aerosols on the Indian summer monsoon, and **Zhenming Ji** discussed simulations of anthropogenic aerosols over South Asia and their effects on the Indian Summer Monsoon based on a regional climate model coupled with a chemistry-aerosol model. Aerosol transport by deep convection and their influence on mesoscale convective systems over the Indian Monsoon Region was presented by **Sudip Chakraborty**, and long term observations of aerosols and trace gases from the NCO-P station, the Indo-Gangetic Plain, and Brahmaputra valley were presented respectively by **Paolo Cristofanelli**, **Sachchidanand Singh**, and **Binita Pathak**. **Sachin Gunthe** made a presentation on the effect of aerosols on climate and human health.

Session 3: Convection and Chemistry (Brice Barret and Hans Schlager)

The session began with an

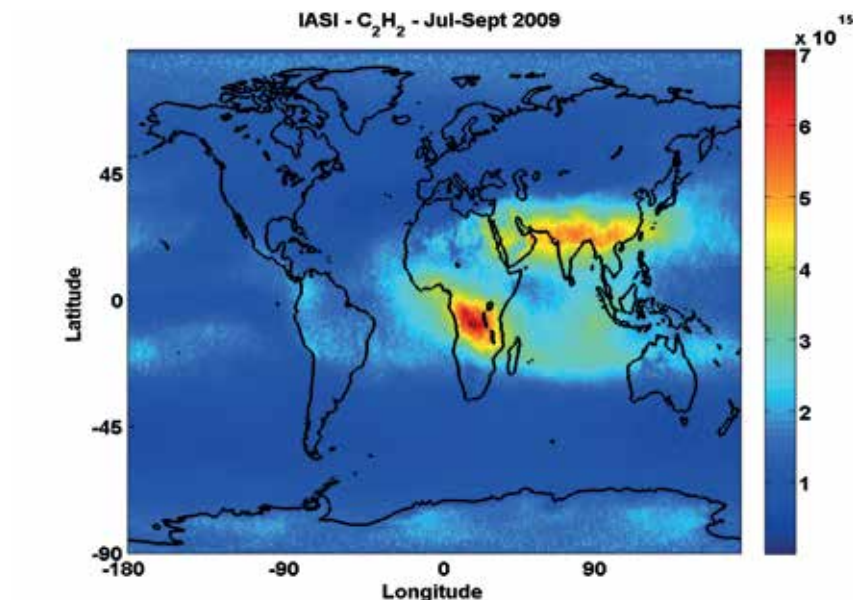


Figure 18: Enhanced acetylene observed by IASI over South Asia during the monsoon season demonstrates the interaction between monsoon dynamics and emissions and is a reminder that *in situ* observations from aircraft are sorely needed. Figure courtesy Cathy Clerbaux, Laboratoire Atmosphères, Milieux, Observations Spatiales.

invited talk by **Mary Barth**, who highlighted the key role of convection in controlling the composition of the atmosphere through the transport of reactive species, scavenging of soluble species, production of NO_x by lightning (LiNO_x), heterogeneous chemistry on ice and water, and photochemistry in clouds. She stressed that the assessment of the impact of convection on chemical composition requires multi-scale modelling capabilities: high-resolution cloud-scale models for convective processes and regional-scale models for south and southeast Asian emissions. Convection also impacts the oxidation capacity of the troposphere as discussed by **Hartwig Harder**, in another invited talk. In particular, LiNO_x and convectively uplifted NO_x are responsible for the enhancement of the OH radical in the upper troposphere (UT), as detected by airborne observations. The underestimation of UT OH by global models may be caused by an incorrect representation of peroxides and an overestimated

removal of OH by isoprene. Therefore additional *in situ* observations of NO_x and organic VOCs in the UT are needed to better constrain models. Orographically-induced transport processes also play a key role in controlling the regional tropospheric composition, as highlighted by **Arnico Panday**. His presentation focused on the transport of pollution from Nepal to Tibet by strong up-valley winds. Instrumented stations along the Kali Gandaki valley in the Himalayas enabled the determination of large BC fluxes. Space-borne observations were also emphasized as a tool to help understand the interplay between chemistry and convection. **Brice Barret** showed that the IASI sensor could help characterize the intraseasonal variability of tropospheric and UT ozone and validate global modelling of the monsoon period in Asia. **Cathy Clerbaux** provided examples of the usefulness of IASI data to characterize tropospheric carbon monoxide distributions and strong pollution events over China (**Figure 18**).

Sachiko Hayashida highlighted the importance of space-borne methane data (SCIAMACHY, IASI, GOSAT) to constrain the emissions from rice paddies. Measurements of C-isotopes for VOC samples collected from the HALO aircraft were presented by **Ralf Koppmann**. Such measurements, already performed at high latitudes, could provide a powerful tool to document the sources, chemical aging, and transport processes of VOCs during the Asian monsoon. Convective precipitation is responsible for the deposition of soluble ions, which is an important issue for Asian populations. Measurements of soluble ions in precipitation were presented for stations around Pune by **Prakasa Rao** and Kathmandu by **Lekhendra Tripathi**. **Mary Barth** stated that correlative measurements of BC at these stations would help determining the scavenging of BC by precipitation, which is poorly known.

Future work on the topic of convection and chemistry requires the establishment of priorities from the regional research communities and putting forward new projects that will provide opportunities for international collaborations including Asian partners.

Session 4:

UTLS Response to the Asian Monsoon (Paul Konopka and Jianchun Bian)

Rong Fu (invited talk) evaluated the influence of climate variability and aerosols on convective transport to the UTLS in the Asian summer monsoon (ASM) region using sensitivity studies carried out with the NCAR WACCM chemistry-climate model. She discussed surface temperature variation within the monsoon regions (American vs. Asian monsoon, in particular the Tibetan plateau) in determining

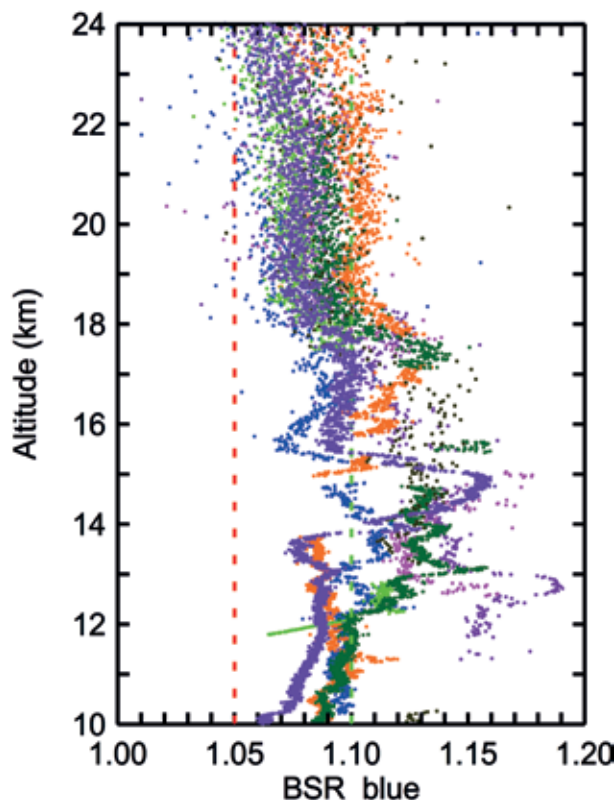


Figure 19: Profiles of the 455nm backscatter ratio from the 18 COBALD (Compact Optical Backscatter Aerosol Detector) sondes launched from Kunming, China, in August 2012. These soundings provide the first in situ corroboration of the Asian tropopause aerosol layer. Figure courtesy Jianchun Bian, Chinese Academy of Sciences.

stratospheric water vapour.

Transport across the tropical tropopause layer (TTL) was discussed by **Bernard Legras** (invited talk). Using diabatic heating rates, he showed that clouds over the ASM region are important to quantify vertical transport into the stratosphere, although some disagreements among different reanalyses need further investigation. He also showed how satellite observations of clouds could be used to parameterize convection in backward trajectory studies.

Jianchun Bian introduced balloon soundings of water vapour, ozone, and particles (SWOP) made from Lhasa and Kunming during the last few summers. He reported the first *in situ* observations within the ASM anticyclone (**Figure 19**). Observations of supersaturation and enhanced aerosols in the tropopause layer were also presented.

Lower stratospheric water vapour variability was studied by **Chiara**

Cagnazzo using several state-of-the-art GCMs. However, these climate models do not reproduce the observed trends in water vapour well, nor do the simulated trends in the ASM anticyclone match the observations, hinting that there is missing physics in our understanding of some key processes.

Transport into the stratosphere via the ASM anticyclone was presented by **Matt Hitchman**, who indicated that breaking Rossby waves around the anticyclone (“shedding of potential vorticity (PV)”) drive the isentropic transport between the ASM region and the stratosphere.

Using model simulations, **Ryan Neely** attributed the presence of the Asian Tropopause Aerosol Layer (ATAL), as observed by CALIPSO, mainly to the emission of sulfur dioxide in Asia. Contrary to the natural sulfur aerosol above the tropopause, anthropogenic BC-related aerosol is dominant below

the tropopause.

In a case study, **Hans Schlager** showed that transport via warm conveyor belts effectively delivers pollution into the tropopause inversion layer, where enhanced formation of sulfate aerosol was inferred. The signal of in-mixing of stratospheric air into the TTL was attributed to the ASM anticyclone.

Archana Shrestha studied “cloudburst” dynamics in the Nepal Himalayas from the view of tropical-extra-tropical interaction at the tropopause level, finding that the ASM circulation pattern and PV anomalies cause enhanced moisture transport into the upper troposphere.

Using volcanic plume signatures emitted by the Eritrean Nabro volcano in 2011 and detected in Envisat-MIPAS and CALIOP satellite observations, **Marc von Hobe** discussed the ASM as a vertical transport pathway into the stratosphere. Trajectory studies show that air masses lifted by the ASM can reach the upper branch of the Brewer Dobson circulation with the onset of the boreal winter. **Federico Fierli** discussed the ASM as a vertical transport pipe carrying atmospheric trace gases from the boundary layer into the UT, among which, the south Tibetan Plateau and North Indian regions have the strongest source impact.

A study of the dynamical and chemical structure of the ASM anticyclone in the UTLS was presented by **Laura Pan**. Using a specified-dynamics run of the WACCM model, she showed that the ASM anticyclone has a strong intraseasonal oscillation at the UTLS level between an Iranian and a Tibetan plateau mode. These oscillations in geopotential height anomalies and the chemical

tracer field were found to be well correlated.

Summary Session and Next Steps

The meeting culminated with a summary session focused on how to continue the community building effort initiated by the workshop. Representatives from IGAC, SPARC, and iLEAPS outlined perspectives and advice from their respective organizations. **Bill Randel** provided an introduction to the CCMI project on behalf of SPARC, and invited the interests of the participants. **Hiroshi Tanimoto** presented a discussion for the plan to establish an IGAC-Asia working group. **Mary Barth** presented iLEAPS’ interest in developing a regional node. **Greg Carmichael** presented a summary of the recent international workshop on “Changing Chemistry in Changing Climate: Monsoon 2013” in Pune, India, which had overlapping themes with the ACAM workshop. This was followed by overviews of a number of upcoming ACAM relevant projects. **Markus Rex** presented an overview of the European joint project StratoClim, which includes a plan for a field campaign focused on the Asian monsoon impact on the UTLS. **Iq Mead** presented the plan for a sounding network of ground-based stations for carbon monoxide, ozone, and carbon dioxide, involving a number of Southeast Asian stations. **Bob Yokelson** presented a plan for a collaborative effort of ground-based fire emission sampling in Nepal and Bhutan in support of airborne campaigns.

The final open-floor discussion proved to be the highlight of the workshop. Participants from a broad spectrum of experience

including graduate students, young faculty, and senior scientists, spoke up to express what follow-up activities they would like to see. A clear consensus emerged in favour of forming an ACAM initiative or working group to continue with community building activities. Suggested activities included convening a regular ACAM workshop on an annual or biennial interval, organizing data sharing, modelling training sessions, summer schools for Asian monsoon regional countries, young scientist forums, and coordinated participation of local researchers in future international field campaigns. The invited talks are already posted and available for download from the ACAM website (<http://www.acd.ucar.edu/utls/2013/>). Details on future meetings and follow-up activities will be announced on the website. Interested researchers may also join the ACAM mailing list to become involved with this group (at the same website).

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5th SPARC General Assembly: A brief look back

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From 12-17 January 2014 nearly 300 scientists from around the world participated in the 5th SPARC General Assembly. Held in picturesque Queenstown, New Zealand, the conference provided a unique platform for interdisciplinary exchange of science related to ‘Stratosphere-troposphere Processes And their Role in Climate’. The local organising committee, G. Bodeker, E. Scarlet, K. Kreher, and S. Kremser, did a fantastic job in making the entire event a wonderful success – from the logistics to the social events, including a trip across the spectacular Lake Wakatipu for the conference dinner at a traditional New Zealand sheep farming station.

The science focused on six main themes: ‘Emerging and outstanding research of relevance to SPARC’, the theme of the first Sunday afternoon session; ‘Atmospheric chemistry, aerosols, and climate’; ‘Stratosphere-troposphere-ocean dynamics and predictability of regional climate’; ‘Coupling to the mesosphere and upper atmosphere’; ‘Observational datasets, reanalyses, and attribution studies’; and ‘Tropical Processes’. Each of the latter five themes had dedicated poster sessions, and, as is tradition, much emphasis was placed on these sessions since they provide unrivalled opportunities for in-depth discussions and scientific exchange at all levels. Most of the presentations and posters are available online and can be downloaded from: <http://www.sparc-climate.org/meetings/general-assembly-2014/>. In addition, the meeting hosted special topics lunch seminars and provided a venue for side meetings for several new and ongoing



Powhiri - Maori welcome dance



Official opening by Prof. Jim Metson



Steaming to the Conference dinner.



1-minute pitches on posters

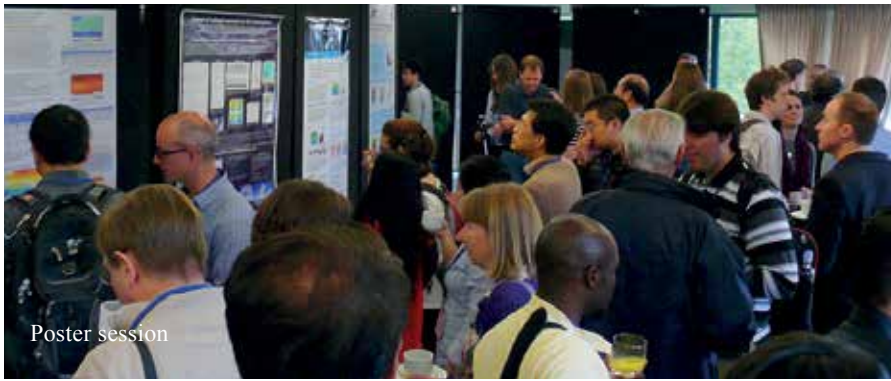


Greg Bodeker at the welcome address

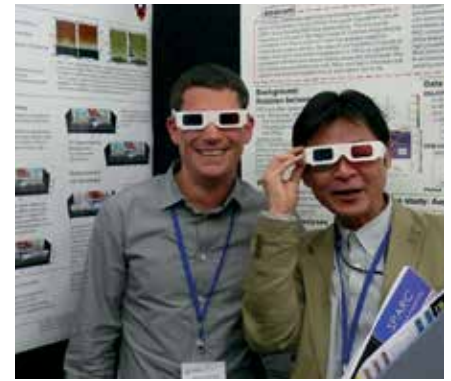
SPARC Activities. Watch for more in-depth reports in the July newsletter.

The 5th SPARC General Assembly was an overwhelming success, enjoyed by all participants. Special thanks are owed to the local organising committee, the scientific organising committee (V. Eyring, A. Scaife, J. Arblaster, D. Fahey, J.-F.

Lamarque, M. Santee, K. Sato, and P. Young), and those at the WCRP Joint Planning Staff for all their hard work and effort in making the whole event possible. Special thanks are due to all sponsors: Platinum – WCRP; Gold – WMO, WIGOS, GAW, WWRP, NSF, APN; Silver – CSA, ARC, NIWA, ESA, SPARC Project Office; and Bronze – Antarctic New Zealand, COSPAR,



Poster session



Participants at the 2014 SPARC General Assembly.



Queenstown



Ice-breaker event



Gerald Meehl at the Opening lecture

Tofwerk, Aerodyne Research, Bodeker Scientific, Macquarie University, and the University of Otago.

New SPARC Logo

The SPARC 5th General Assembly was also the occasion for the official launch of the new SPARC logo. The new, professionally designed logo was chosen through a community effort, and highlights the evolution of SPARC and its new name – Stratosphere-troposphere Processes And their Role in



Conference dinner

Climate. SPARC's new name reflects the WCRP's internal restructuring and the extension of SPARC's fo-

cus also to those aspects of tropospheric climate that have a link to the stratosphere.

SPARC meetings

31 March-4 April

Gravity Waves ISSI meeting, Bern, Switzerland

5-9 May

5th SOLARIS/HEPPA Workshop, Baden Baden, Germany

20-22 May

IGAC/SPARC Chemistry Climate Modelling Initiative Workshop, Lancaster, UK

SPARC-related meetings

12-15 May

MOZAIC-IGOS Scientific Symposium, Toulouse, France

2-10 August

40th COSPAR Symposium, Moscow, Russia

23-28 August

SCAR 2014 Open Science Conference, Auckland, New Zealand

22-26 September

13th IGAC Science Conference, Natal, Brazil

13-17 October

The Climate Symposium 2014, Darmstadt, Germany

www.sparc-climate.org/meetings/

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Towards a paperless newsletter

SPARC is moving towards a paperless newsletter edition. Please let the SPARC Office know if you prefer to receive the newsletter in its electronic form: office@sparc-climate.org.

Photo: Members of the SPARC Scientific Steering Group, leaders and contributors to activities, and the SPARC Office (January 2014).



Imprint

Editing

Fiona Tummon

Design/layout

Carolin Arndt

Print & distribution

ETH Zurich

ISSN 1245-4680

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