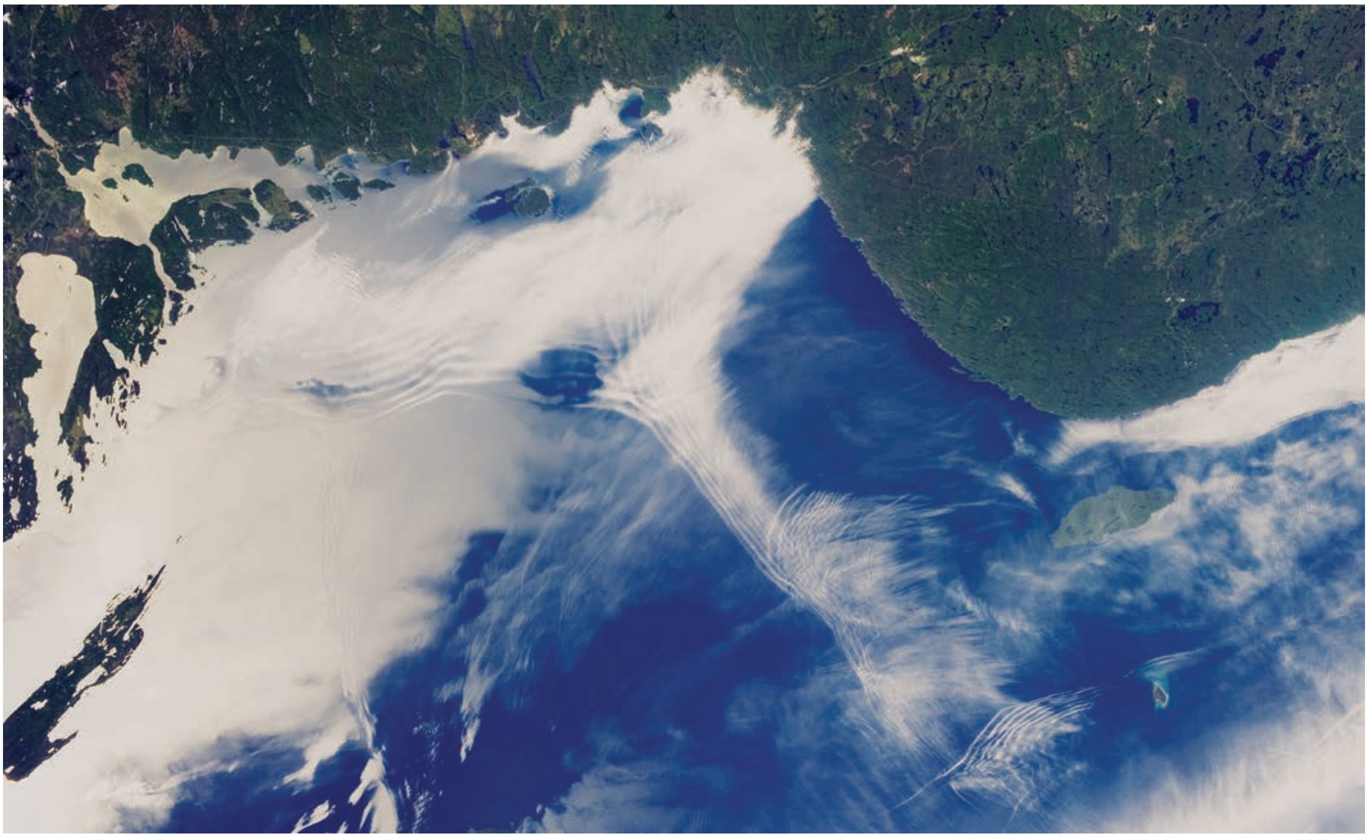
SPARC
Stratosphere-troposphere
Processes And their Role in Climate

newsletter n° 44
January 2015

www.sparc-climate.org



From the vantage point of the International Space Station a great variety of atmospheric phenomena is visible. Here, gravity waves are seen over northeastern Lake Superior. Gravity waves form due to disturbances in the atmospheric flow where buoyancy acts as the restoring force on air parcels displaced from hydrostatic equilibrium. They play a central role in a broad range of processes extending from the Earth's surface all the way to the upper atmosphere. Image courtesy NASA (William L. Stefanov (Jacobs/JETS) and Michael H. Trenchard (Barrios/JETS), NASA Johnson Space Centre) – [**http://www.nasa.gov/content/gravity-waves-and-sunglint-lake-superior/#.VLzQKmTF-q5**].

Contents

Report on the 35th Session of the JSC of the World Climate Research Programme 2

Gravity Wave Dynamics and Climate: An Update from the SPARC Gravity Wave Activity ...9

Report on the 2nd Joint SOLARIS-HEPPA Meeting ...14

Report on the MOZAIC-IAGOS Scientific Symposium on Atmospheric Composition Observations by Commercial Aircraft: 20th Anniversary 18

Report on the Latsis Symposium: 'Atmosphere and Climate Dynamics' 24

Report on the SPARC Workshop on Polar Stratospheric Clouds ..26

Report from the 10th SPARC Data Assimilation Workshop and the 2014 SPARC Reanalysis Intercomparison Project (S-RIP) Workshop 31

Vladimir Ryabinin – SPARC liaison at WCRP Joint Planning Staff: 2002-2015 38

Johannes Staehelin's retirement: a personal view 39

WCRP World Climate Research Programme
WMO
UNESCO
IOC
ICSU International Council for Science

Report on the 35th Session of the Joint Scientific Committee of the World Climate Research Programme 29 June – 4 July 2014, Heidelberg, Germany

Johannes Staehelin[1], Joan M. Alexander[2], and Fiona Tummon[1]

[1]SPARC International Project Office, Zurich, Switzerland, **johannes.staehelin@env.ethz.ch**,
[2]Northwest Research Associates, Boulder (CO), USA

Antonio Busalacchi (chairperson of the Joint Scientific Committee (JSC), which oversees WCRP) opened the meeting by welcoming all participants, introducing the new chairs and co-chairs of WCRP bodies, as well as by thanking the host institution. He continued with an overview of WCRP's mission and objectives, namely the study of climate variability and prediction, and the understanding of anthropogenic influence on climate. He emphasized that these studies need to be focused on providing benefit and value to society. This implies supporting climate-related decision making and planning for adaptation to climate change through coordinated research (WCRP strategic framework 2005-2015). Several recent assessments by sponsors of international programmes, including WCRP, also stressed the importance of societal needs. He presented a number of action items from the 34th session of JSC (see SPARC newsletter 42), including whether the new WCRP structure would lead to a 'gap' in terms of who is responsible for atmospheric dynamics. He also mentioned that collaboration between WCRP and Future Earth will need further discussion, as addressed in the partnership report of EC66 (66th Executive Council) of the World Meteorological Organization (WMO). Furthermore, he pointed out the important role of the Grand Challenges (see below) in WCRP's new organizational structure.

Paul Becker, vice president of the German Weather Service (Deutscher Wetterdienst) welcomed all participants on behalf of the meeting hosts. He discussed the meeting on 'New Climate Research and Operational Challenges and Perspectives' organized by the WMO's Commission on Climatology, which took place in parallel to the JSC meeting, with one day in common between both meetings. He further addressed the importance of climate services, but also stressed the need for cost effectiveness and extensive communication with end-users.

David Carlson, new director of WCRP's Joint Planning Staff (JPS) following on from Ghassem Asrar, acknowledged the important contribution of all JPS staff and also that of the core project International Project Offices (IPOs). He presented the budgets of the four IPOs, which are supported through national resources, as well as overall WCRP budget information, including allocation for WCRP-supported meetings.

Dialogue with WCRP Sponsors

Jeremiah Longoasa, WMO Deputy Secretary-General, pointed out the important links and cooperation between WCRP and WMO, for example, in terms of the IPCC (International Panel on Climate Change) and GFCS (Global Framework for Climate Services). He also discussed the creation of a common office between the World Health Organization (WHO) and WMO, since climate services has become an important element of WHO's agenda. Jeremiah supported Antonio's view of Future Earth and mentioned that the African climate change science community is eager to continue work in this regard, as discussed at the WCRP African Climate Conference that took place in Arusha, Tanzania, in 2013. **Filipe Lucio** further discussed GFCS, pointing out that at present about 20 countries are unable to use and support climate services, and thus capacity development is one of the highest priorities of GFCS. Other priorities include high profile projects aimed at addressing specific knowledge gaps, observations and data recovery, interdisciplinary partnerships, and good governance to ensure the climate services framework is successful.

Albert Fischer, Head of Ocean Observations and Services, discussed progress of the Intergovernmental Oceanic Commission (IOC). The IOC's 2014-2021 vision lists several high-level objectives including protection of a healthy ocean ecosystem, effective early warning systems, and increased resilience to climate change. He pointed out that ocean observations are of high priority and are coordinated by the Global Ocean Observing System (GOOS), which is part of GCOS (see below). Essential Ocean Variables (EOV) partially overlap with Essential Climate Variables (ECV) and he stressed the importance of cooperation between GOOS and CLIVAR (see below) to ensure that no efforts are duplicated. GOOS is currently developing three new major projects that will include a deep ocean observing strategy, a Tropical Pacific Observing System, as well as a strategy for Atlantic Ocean observations. These projects were further discussed at the GOOS Steering Committee meeting held in July 2014. Because of IOC funding issues, future support for WCRP will be very limited, however all IOC member states remain firmly committed to WCRP.

WCRP Grand Challenges

The implementation of the six WCRP Grand Challenges, essential elements of WCRP collaborative efforts (see SPARC newsletter 42), was reviewed by the grand challenge leads.

Detlef Stammer presented the Grand Challenge on 'Sea-Level Rise and Regional impact' (lead: CLIVAR). Mean sea-level is expected to rise as a consequence of climate change, however it is expected to vary considerably from region to region and is difficult to predict because of the wide range of physical causes, including climate modes, continental lifting, gravitational changes, ice mass changes, *etc*. Furthermore, uncertainties in terms of the magnitude of each of these individual aspects are difficult to describe. He identified the different communities that will need to contribute to the grand challenge and outlined its structure and work programme.

Graeme Stephens together with **Sonia Seneviratne** discussed the Grand Challenge on 'Changes in Water Availability' (lead: GEWEX). Important elements include the use of new high-quality global satellite precipitation and snowfall products to close the water and energy budgets, as well as using these and other data sources to confront models in innovative ways. In this respect, data availability is vital, as is model development, particularly at higher resolutions to explicitly allow simulation of convective processes. The link between the global energy budget and the water cycle remains critical for this grand challenge and the study of small-scale structures and their dependence on model resolution is viewed as an ideal opportunity for significant progress.

Greg Flato discussed the status of the Grand Challenge on 'Cryosphere in a Changing Climate' (lead: CliC, co-lead: SPARC). The science foci of the grand challenge include: (1) seasonal, interannual, and longer-term predictions of polar climate and the role of the cryosphere in climate predictability; (2) enhanced analysis of model intercomparison results, including CMIP5 (Coupled Model Intercomparison Project 5) and CORDEX (see below), to better understand and attribute model biases to cryosphere components (which is also one of CliC's targeted activities); (3) improved representation of permafrost and high latitude land surfaces (including wetlands) in climate models, with a specific emphasis on their role in the global carbon cycle; and (4) focused efforts on developing ice sheet models, with specific emphasis on the role of ice sheet dynamics on the rate of sea-level rise (with a clear connection to the Grand Challenge on 'Sea-Level Rise and Regional impact').

Ted Shepherd (co-lead) presented the status of the Polar Climate Predictability Initiative (PCPI), which is contributing to the Grand Challenge on 'Cryosphere in a Changing Climate'. PCPI is focused on six initiatives (see SPARC newsletter 42), each led by two champions. Through three of these initiatives, which are jointly carried out with the World Weather Research Programme (WWRP) Polar Prediction Project (PPP), PCPI will be involved in the Year of Polar Prediction (YOPP) being organised from 2017-2019. The YOPP will provide an extended period of coordinated and intensive observational and modelling activities aimed at improving polar prediction capabilities at time scales ranging from hourly to multi-decadal.

Clare Goodess discussed the status of the Grand Challenge on 'Regional Climate Information' (lead: WGRC (see below) together with CLIVAR). A key question relates to the availability of high quality regional observations needed for process understanding, for climate model initialization and evaluation, and for assessing projected changes on all time scales ranging from the subseasonal to the decadal. Another important aspect relates to identifying and understanding processes that improve projections on these various time scales. Finally, the information provided needs to serve as a solid and targeted basis for risk management decisions. The grand challenge is still refining its science questions, identifying projects that are currently addressing them, as well as establishing where research gaps lie. To this end, an expert meeting was organized in Santander, Spain, at the end of October 2014 to review current and planned activities, initiate the writing of a position paper, and frame a research guidance paper. The grand challenge is also integrally linked with the CORDEX activity.

Sonia Seneviratne together with **Graeme Stephens** discussed the Grand Challenge on 'Climate Extremes' (also proposing a new title: 'Understanding and Predicting Weather and Climate Extremes') (lead: GEWEX, in consultation with CLIVAR). A white paper has been finalized and a more detailed implementation plan is being developed. Eight key science foci have been identified: (1) improve the quality of ground-based and remote-sensing datasets for extremes; (2) improve the models used to simulate extremes; (3) better understand the interactions between large-scale drivers and regional-scale land surface feedbacks affecting extremes; (4) establish the role of external forcings (*e.g.* anthropogenic) *vs.* internal variability for changes in intensity and frequency of extremes; (5) identify factors contributing to the risk of a particular observed event; (6) better understand the causes of drought changes in both the past and future; (7) improve the predictability of changes in frequency and intensity of extremes at seasonal to decadal time scales; and (8) better understand the role of large-scale phenomena (*e.g.* monsoons, and other modes of variability) for past and future changes in extremes.

Sandrine Bony discussed the progress of the Grand Challenge on 'Clouds, Circulation, and Climate Sensitivity' (lead: WGCM (see below)). A very successful workshop was held in Ringberg, Germany, in March 2014, which helped drive the development forward. The following principles are relevant to all activities of the grand challenge: (1) a need to link model development to all the activities organized by the grand challenge; (2) the importance of better understanding the water budget of the lower troposphere (across all scales); (3) the value of more closely integrating paleoclimate activities within the grand challenge. Advances in remote sensing that allow three-dimensional global observations of clouds and aerosols in parallel with modelling developments that permit global cloud-resolving simulations, means that it is now possible to bridge the gap between cloud- and large-scale dynamics. The convergence between these two scales will be accelerated through the grand challenge being focused on four key questions: (1) How will storm tracks change in future? (2) What controls the position and strength of the tropical convergence zones? (3) Is convective aggregation important for climate? (4) How does convection contribute to climate feedbacks? Each of these questions will be the focus of a workshop over the next two years, with SPARC the main driving force behind a workshop to be held in Grindelwald, Switzerland, in August 2015 focused on storm tracks.

Core projects

Greg Flato (co-chair) started his presentation on CliC (Climate and Cryosphere Project) by mentioning that CliC has a new co-chair, namely Gerhard Krinner. He presented CliC's action plan in which targeted activities with limited lifetimes have been selected. Particular emphasis has been placed on modelling, with the action plan including a polar CORDEX activity as well as activities focused on ice modelling, snow modelling, and modelling of the interactions between the Antarctic ice shelf and surrounding oceans. Several of these modelling activities will contribute to CMIP6 (see below). Other activities covered in the action plan include: arctic freshwater, polar jet stream variability and extremes, improved Greenland mass balance estimation, and carbon cycle feedbacks in a changing Arctic climate. Greg also pointed out that CliC's 'core research' overlaps to a large degree with the grand challenges 'Cryosphere in a Changing Climate' and 'Regional Sea Level Rise', to which CliC will contribute significantly.

In his report on GEWEX (Global Energy and Water Exchanges), **Graeme Stephens** (co-chair) summarized the new structure of the project, which is based on four panels as well as additional task force groups and activities that work between these panels. The GASS (Global Atmospheric System Studies) panel focuses on improving observations and models to better simulate the atmospheric system in both weather and climate models. The GLASS (Global Land/Atmosphere System Study) panel is aimed at promoting community research to develop model representation of the land surface, as well as to improve understanding of land-atmosphere feedbacks and the role of land surface in climate predictability. GLASS has important links to the carbon community and has joint activities with the IGBP (see below) project iLEAPS (Integrated Land Ecosystem Atmosphere Process

Study). The GEWEX Data and Assessments Panel (GDAP) works on GEWEX reference products and is particularly involved in their validation and assessment. SPARC is contributing upper tropospheric humidity data for the GDAP water vapour assessment (G-VAP). Finally, the GEWEX Hydroclimatology Panel (GHP) covers several regional hydroclimate projects as well as cross-cutting projects that involve other WCRP bodies.

Joan Alexander (co-chair) started her presentation by mentioning SPARC's new name 'Stratosphere-troposphere Processes And their Role in Climate' and new logo. The 'whole atmosphere' approach has always been integral to SPARC, with the atmosphere, from the troposphere all the way up to the mesosphere, being viewed as one system. She continued by presenting an overview of the very successful SPARC General Assembly held from 12-17 January 2014 in Queenstown, New Zealand (see SPARC newsletter 43). She also presented results from several SPARC activities, highlighting the release of the sixth SPARC report 'Lifetimes of stratospheric ozone-depleting substances, their replacements, and related species', which contributed significantly to the 2014 WMO/UNEP Ozone Assessment. In her preview of the new 2015 SPARC implementation plan, Joan mentioned the three proposed themes: 'chemistry in climate', 'atmospheric circulation in climate', and 'long-term records in climate'. With these themes as foci, SPARC will continue to contribute to several grand challenges through its activities and a number of workshops and conferences. Furthermore, activities such as CCMI (Chemistry Climate Modelling Initiative), a joint activity with IGAC (International Global Atmospheric Chemistry), will contribute to CMIP6 through the provision of forcing data sets as well as by proposing a MIP jointly with AeroCom – the AerChemMIP.

Detlef Stammer (co-chair) presented the evolution of CLIVAR (Climate Variability And Predictability Project). CLIVAR is developing a new science plan and implementation strategy, covering a new set of research foci that are aimed at contributing to the WCRP grand challenges as well as to the wider aim of better understanding the role of the oceans in climate change and variability. CLIVAR would also like to intensify partnerships with the marine biochemistry and ecosystem communities. The ICPO (International CLIVAR Project Office) is no longer based in the UK, but has two regional nodes based in India and China, with support from these two countries as well as the USA. The new CLIVAR structure is also based on core panels, such as the Ocean Model Development Panel and a new Monsoon Panel in cooperation with GEWEX. The Climate Dynamics Panel has many links within WCRP, including with SPARC. Detlef also brought up the possibility of a joint CliC/CLIVAR Arctic Panel and discussed the continuation of cooperation with the IGBP project PAGES (Past Global Changes). Finally, he discussed whether an ocean alliance should be part of the collaboration between WCRP and Future Earth.

WCRP councils

A major focus of **Otis Brown**'s presentation on WDAC (WCRP Data Advisory Council) focused on Obs4MIPs (Observations for Model Intercomparison Projects). The Obs4MIP database is hosted on the ESGF (Earth System Grid Federation) and currently contains a wide range of observational data sets ranging from sea surface temperatures to cloud and aerosol profiles. Data from ESA (European Space Agency) are being prepared and evaluated for integration into the database as well. Challenges remain however, including the provision of a streamlined 'recipe' for preparation of Obs4MIPS data sets, guidelines and requirements for submission of data, as well as specific measures of data quality. WDAC discussed these and many other issues at their third annual meeting, hosted in Galway, Ireland. WDAC recommended that the JSC endorse the use of open access journal citations and digital object identifiers (DOIs) so that data sets can be easily cited and the efforts of data producers more widely recognized. WDAC also established a WCRP-wide 'Surface flux task team', which is to identify and address gaps in the surface flux observing system.

In his presentation on WMAC (WCRP Modelling Advisory Council), **Christian Jacob** (co-chair) discussed model development, particularly within the context of regional climate change, as well as the modelling needs related to ESGF and CMIP. He argued that model development is not always adequately addressed and he stressed the need for modelling-related aspects to be presented in reports from core projects, working groups, and grand challenges. In terms of ESGF, Christian pointed out that model development requires advanced diagnostics and analyses, the data for which is currently lacking in ESGF. WMAC is organizing a WCRP-wide conference on model development to be held in 2017 or 2018, as well as a summer school on the 'Representation of clouds and convection in atmospheric models' being hosted by the Max Planck Institute in 2015. Furthermore, a 'WCRP/WWRP International prize for model development' has been established. Finally, it was noted that no atmospheric dynamics 'gap' was created by the reorganization of WCRP since atmospheric dynamics is important in many projects. It was, however, suggested that SPARC gather information regarding all WCRP atmospheric dynamics-related activities and that this inventory be presented on a common website to improve coordination efforts.

WCRP Working Groups

Clare Goodess (co-chair) reported on the Working Group for Regional Climate (WGRC), who recently established several terms of reference: (1) to facilitate coordination of WCRP research activities relevant to the provision of regional climate information and related climate services; (2) to integrate the regional user and decision maker context into the design and development of regional climate science through two-way communication and co-production activities; (3) to facilitate, in cooperation with other relevant international organisations, the provision of good practice guidance for potential users on identification, selection, processing, application, and interpretation of regional climate information; (4) to provide advice to the WCRP regarding research activities needed to support and improve regional climate science and prediction; and (5) to oversee and promote specific WCRP regional climate initiatives, including CORDEX. The WGRC is to serve as the point of contact between WCRP and regional climate services, as well as with the GFCS and Future Earth. WGRC is working on producing a glossary of definitions of critical variables used by the climate community and on producing papers covering CORDEX-Africa and regional climate information.

Filipo Giorgi presented an overview of the recent developments of CORDEX (WCRP Coordinated Regional Downscaling Experiment). CORDEX has been very successful in triggering many activities, however, the 'explosion' of results has created a need for better coordination and homogenization of CORDEX data. To this end, CORDEX now has a dedicated Project Office based in Sweden who is responsible for data management and distribution, as well as to ensure smoother communication within the CORDEX community and with data end-users. A large amount of data is presently available and some work on empirical down scaling is under way. CORDEX is transitioning into phase II, implying an increase of the 'base' resolution of experiments from 50 to 25km, a reconsideration of the 'base' domains used, as well as the identification of several Flagship Pilot Studies (FPSs). The criteria used to choose FPSs are not yet clear, but will likely be based on, amongst others, key physical science issues/hotspots, potential for funding availability, possibility for interaction with WCRP projects, and the availability of comprehensive high quality observational data.

In her presentation on WGCM (Working Group on Coupled Modelling) and CMIP6 (Coupled Model Intercomparison Project – Phase 6; **http://www.wcrp-climate.org/index.php/wgcm-cmip/about-cmip**), **Catherine Senior** (WGCM co-chair) discussed the new structure of CMIP6, which is aimed at optimal involvement of the community. The scientific focus of CMIP6 is to be framed around the six WCRP grand challenges, as well as an additional theme related to biospheric forcing and feedback (in collaboration with the IGBP AIMES (Analysis, Integration, and Modelling of the Earth System) project). The experimental design will be based on three broad scientific questions: (1) How does the Earth System respond to forcing? (2) What are the causes and consequences of systematic model biases? (3) How can we assess future climate changes given climate variability, predictability, and uncertainties in scenarios? The new organization will include two elements, ongoing Diagnostic, Evaluation, and Characterization of Klima (DECK) experiments that would be carried out by all modelling centres and CMIP6-endorsed MIPs that would focus on particular topics aimed at addressing the different CMIP6 themes. The CMIP6 design and organization was finalized in October 2014.

Francisco Doblas-Reyes (co-chair) reported on the activities of WGSIP (Working Group on Seasonal to Interannual Prediction). The basic modelling questions are related to the progression from initial-value problems with weather forecasting at one end and multi-decadal to century projections as a forced boundary condition problem at the other, with climate prediction (sub-seasonal, seasonal, and decadal) in the middle. Through its activities WGSIP will contribute to all WCRP grand challenges. Current projects include the CHFP (Climate-system Historical Forecast Project), which has a stratospheric sub-project (see SPARC newsletter 43), and WGSIP is also involved in the WCRP/WWRP S2S (sub-seasonal to seasonal predictions) project. Francisco also discussed several technical issues related to moving WGSIP data to the ESGF and the conflict between various formats used between research and operational forecasts.

Jean-Noël Thépaut (co-chair) started his presentation on WGNE (Working Group on Numerical Experimentation) by recalling that WGNE is a joint working group established by WCRP and the WMO Commission for Atmospheric Sciences. Its main goals include supporting the development of atmospheric circulation models for use in weather prediction and climate studies covering all time scales. WGNE coordinates a number of projects, including for example, evaluating the impacts of aerosols on numerical weather prediction or comparing the surface drag of different models. WGNE is to support S2S, PPP, and CMIP6, and will continue to maintain strong links with many other WCRP bodies, including SPARC.

Sarah Jones (incoming chair of the scientific steering committee) gave an overview of WWRP (World Weather Research program of WMO). The WWRP strategic plan integrates a wide variety of WMO member activities involved in THORPEX (The Observing system Research and Predictability Experiment), tropical meteorology, mesoscale weather forecasting, nowcasting (including its verification), as well as societal and economic applications. The plan maintains and reinforces links with WMO Global Atmosphere Watch, WCRP, as well as other WMO activities. WWRP has already produced many tangible results that have been incorporated into operational forecasting, but many challenges remain. These include continuing to bring together the research and operational communities, enhancing focus on priority operational needs, and maintaining focus on training of young scientists, particularly from developing countries. The work of WWRP is also very strongly linked to WCRP and GFCS, with the aim of providing seamless forecasts from minutes to months and beyond to climate, through projects such as S2S and PPP.

WCRP partnerships and Joint Initiatives

Stephen Briggs (Steering Committee co-chair) discussed GCOS (Global Climate Observing System) and its connection to other international organizations. Observations are vital in terms of all aspects of climate science and Stephen highlighted how essential they are to GFCS. GCOS functions through a number of panels, several of which have close connections with WCRP, for example, the Atmospheric Observation Panel for Climate (AOPC) or GOOS. As part of its strategy, GCOS also produces 'adequacy' reports aimed at assessing particular observations or networks, for example satellite observations. These assessments determine what observations are needed (including ECVs), whether all requirements are fulfilled, or which improvements might be needed. He also mentioned that GCOS is strongly influenced by the requirements of the modelling community. GCOS is to produce status and progress reports as well as an assessment of the global climate observation system by the end of 2015. These will feed into its new implementation plan due in 2016.

Hartwig Kremer presented PROVIA (Programme of Research on climate change Vulnerability, Impacts, and Adaptation), which is supported by UNEP, WMO, and UNESCO. PROVIA is understood as the interface between the research community and decision makers and represents the social science perspective of climate change. PROVIA research activities are focused on advancing policy-relevant research, which includes monitoring and gauging levels of vulnerability, progress in adaptation and resilience, as well as studying historical cases to guide future responses. Furthermore, PROVIA is heavily engaged in coordinating and facilitating the dissemination of information of practical application to end-users. Finally, development and training workshops are also a vital part of PROVIA's activities, including mentoring and young scholar fellowships.

Steven Wilson, executive director of ICSU (International Council for Science), started his presentation by pointing out that ICSU aims to strengthen international science for the benefit of society. A review of ICSU, the first since 1960, is currently under way. Besides the programmes that are to be integrated into Future Earth, ICSU is involved in several initiatives, namely IRDR (Integrated Research on Disaster Risk) and START (global change SysTem for Analysis, Research, and Training). **Frans Berkhout**, acting director of Future Earth (until the end of 2014), made a remote presentation about the implementation of the programme. Future Earth is a global platform for scientific collaboration that is to: (1) enable integrated research on challenges along the path to sustainability; (2) strengthen partnerships between researchers, funders, and end-users; (3) build solution-oriented knowledge needed to accelerate transformation to sustainability; and (4) communicate science to society and vice versa. As a first step, the US National Science Foundation has funded several fast-track initiatives. Of the 52 proposals received 8-10 initiatives have been funded, covering topics such as the global nitrogen cycle, and sub-seasonal to seasonal forecasts for Africa. Projects from the International Human Dimensions Programme and Diversitas will be integrated into Future Earth by the end of 2014 and those from IGBP (see below) will follow by the end of 2015. More information on the status of the implementation of Future Earth can be found at **www.futureearth.info**.

Sybil Seitzinger, executive director of IGBP (International Geosphere–Biosphere Programme), discussed how the programme is evolving during its integration into Future Earth. The programme formally comes to an end in December 2015, with its core projects then becoming part of Future Earth. Because of the significant overlap between IGBP and WCRP research, she asked about future collaborations and connections between WCRP and specific IGBP projects (*e.g.* IGAC, SOLAS (Surface Ocean - Lower Atmosphere Study), and PAGES). She proposed that joint projects be considered, for example, a Global Carbon Project or a Global Water System Project. She also asked whether a climate cluster in Future Earth, incorporating these joint projects, would be appropriate. IGBP is also presently working on the IGBP Landmark Synthesis to frame IGBP's contributions to global environmental change research, which will be completed by the end of 2015.

Concluding Session and next JSC meeting

Guy Brasseur (SSG member) briefly presented the agenda of the IPCC AR5 workshop 'Lessons learnt for climate change research and WCRP', which was held in Bern, Switzerland, from 8-10 September 2014. He asked whether the agenda was appropriate for WCRP to take advantage of lessons learnt by IPCC, and whether there was sufficient space to discuss new activities beyond the grand challenges. **Roberta Boscolo** then reported on YESS (Young Earth System Scientist community). In the final discussion it was noted that the collaboration between WCRP and Future Earth needs further clarification and all communication is presently going through the chair of the JSC. SPARC agreed to conduct a survey to collect information about atmospheric dynamics projects currently underway (or planned) from all WCRP bodies. The JSC proposed that Guy Brasseur follow Antonio Busalacchi as new JSC chair as of January 2015. The 36th JSC meeting is scheduled for 8-10 April 2015 and will take place in Geneva, Switzerland.

All presentations from the 35th JSC meeting are available at: **http://www.wcrp-climate.org/JSC35/agenda.html**.

Gravity Wave Dynamics and Climate: An Update from the SPARC Gravity Wave Activity

M. Joan Alexander[1] and Kaoru Sato[2] (Co-leaders of the SPARC Gravity Wave Activity)

[1]North West Research Associates, Boulder, CO, USA, **alexand@cora.nwra.com**,
[2]Department of Earth and Planetary Science, University of Tokyo, Tokyo, Japan.

The SPARC Gravity Wave Activity in recent years has placed a focus on the role of gravity waves in driving the general circulation of the stratosphere. While planetary-scale Rossby wave-driving clearly dominates the stratospheric circulation, small biases in the zonal-mean zonal winds can have very significant effects on Rossby wave propagation. Parameterized gravity wave (GW) drag in climate models is a primary tool used to reduce zonal-mean wind biases, and hence small-scale GWs can have larger impacts by helping to shape the propagation pathways of the more dominant Rossby waves. Contribution of GWs to the stratospheric circulation in the summer hemisphere may be particularly important because Rossby waves rarely propagate in easterly winds. In the tropical stratosphere, GWs and larger-scale waves play an approximately equal role in driving the quasi-biennial oscillation (QBO; *e.g.* Kawatani *et al.*, 2010). This gives small-scale GWs an important role in regional climate through shaping teleconnection pathways. For example, Scaife *et al.* (2014) show that the QBO is an important factor in forecasting the North Atlantic Oscillation. GWs also have a role in long-range weather forecasting through their influence on planetary wave propagation and sudden stratospheric warmings (Sigmond and Scinocca, 2010; Wright *et al.*, 2010; France *et al.*, 2012; McLandress *et al.*, 2012; Tomikawa *et al.*, 2012; Sigmond *et al.*, 2013). Improving the realism of these processes in global models requires realistic GW drag forces, including their distributions with latitude and height, and their changes over the broad range of timescales for weather and climate applications. However, determining what is realistic is a challenge.

The GW activity has thus been focusing on (1) using observations and models to constrain GW momentum fluxes (the GW contribution to Eliassen-Palm flux), (2) developing methods for constraining GW forces on the circulation, and (3) identifying important sources of GW momentum flux and quantifying their geographical and seasonal variations.

In 2013 a group from the activity published their comparison of GW momentum fluxes in observations and models (Geller *et al.*, 2013). The results showed surprisingly good agreement among climate models in how much total absolute GW momentum flux is needed to obtain a reasonable simulation of the middle atmospheric circulation. Limb-scanning satellite observations have been used to derive momentum flux estimates with global coverage over three or more years, however these remain severely limited by sampling resolution: Momentum fluxes estimated from satellite observations are significantly smaller than parameterized fluxes in climate models because of limitations on the wavelengths of waves that can be observed. The satellite measurements also do not currently provide any directional information on the fluxes, and observational filtering can give the appearance that waves have dissipated when in fact they may simply not be visible due to sampling.

The above factors combine to make it impossible to directly compute the GW drag force from current satellite measurements alone. Ern *et al.* (2011) examined vertical gradients in satellite-derived GW momentum fluxes and discussed these as 'potential accelerations' of the wind. More recently Ern *et al.* (2014) refer to these gradients as GW 'drag', but members of the activity want to caution that calling this quantity 'drag' is misleading. Radiosonde profiles can also provide a measure of GW momentum flux, but as with most measurement types, the sampling limitations greatly restrict the portion of the full GW spectrum that can be observed. Measurements from long-duration super-pressure balloons (Vincent and Hertzog, 2014) offer the most accurate global-scale GW momentum flux data. Momentum fluxes derived from these balloon data include directional information and cover the full range of the GW frequency spectrum (Rabier *et al.*, 2013; Jewtoukof *et al.*, 2013), although these data are quite limited in area and time and provide data at only one altitude. So again, drag cannot be computed from these data alone. New measurements from the Antarctic MST/IS radar can provide vertical profiles of GW momentum fluxes and drag with high time-resolution but only at a single location, and need additional modeling studies to examine horizontal distributions of the drag (Sato *et al.*, 2014). Thus the GW force on the global circulation remains something not yet possible to derive directly from observations.

Global GW drag can be estimated with data assimilation techniques (Pulido and Thuburn, 2005; McLandress *et al.*, 2012). Pulido (2014) describes a new and simple method for deriving unresolved (or 'missing') drag in the extra-tropical stratosphere based on potential vorticity inversion. Pulido (2014) applied the method to an idealized model constrained by observations from reanalysis, and also showed errors that can result from estimating GW drag directly from assimilation wind increments. In particular, the wind increment method can produce erroneous latitudinal and longitudinal structure if the drag force is spatially localized.

Since GW drag is now recognized as an important component of atmospheric models used for regional climate prediction and long-range weather forecasting, new emphasis lies on including realistic sources of GWs as well as testing and improving GW parameterization methods for global models. Parameterizations that permit climate and weather feedbacks on sources are being included in more models (Richter *et al.*, 2010; Kim *et al.*, 2013; Schirber *et al.*, 2014a; Richter *et al.*, 2014a,b), and experiments with these models show some intriguing connections between the stratosphere and the surface. For example, Richter *et al.*, (2010) show how changes in surface friction create a chain reaction on orographic GWs, planetary waves, and sudden stratospheric warming frequency. In the tropics, sensitivity to the details of the method of GW parameterization has been shown to strongly influence predicted changes in the QBO period (Schirber *et al.*, 2014b). It is clear that changes in the strength of the QBO have occurred in recent years (Kawatani and Hamilton, 2013), an observation that puts new emphasis on the importance of longer-term QBO prediction. At extra-tropical latitudes, GW sources include not only flow over topography, but also precipitating storms, fronts, and jets (Hoffmann *et al.*, 2013; Alexander and Grimsdell, 2013; Hendricks *et al.*, 2014). Plougonven and Zhang (2014) provide a review of research on jet and frontal sources. Theoretical studies of GW radiating from these sources continue (*e.g.* Yasuda *et al.*, 2014a,b). Sources of GWs are clearly very intermittent (Hertzog *et al.*, 2008; 2012; Wright *et al.*, 2013) and new stochastic parameterization methods better capture this intermittency (Eckermann *et al.*, 2011; Lott *et al.*, 2012) as well as more realistic effects on the stratospheric circulation.

Other new work related to parameterization methods examines horizontal and time-dependent GW propagation, which are neglected in most climate model parameterizations (Choi and Chun, 2013; Kalisch *et al.*, 2014). The ray-based parameterization method of Song and Chun (2008) includes these effects, but the computational costs currently prohibit application of such methods in long-term climate runs. Several global modelling groups are instead running short-term climate and weather simulations at extremely high resolution, where these effects can be explicitly resolved (Sato *et al.*, 2012; Preusse *et al.*, 2014). Although analyses of waves in such high-resolution simulations suggest much of the GW spectrum remains unresolved (**Figure 1**), continuing studies with high-resolution models are beginning to reveal details about GW sources and propagation that assist in the interpretation of observations.

One way that GWs and chemistry are linked is through the stratospheric transport circulation (or residual circulation). The role of GWs in this circulation is a research area ripe with new developments. Climate models almost uniformly predict an increasing trend in the strength of the transport circulation in the next century, and the role for GWs in this trend is still debated. Different models have different recipes for planetary wave, synoptic wave, and GW contributions to driving the stratospheric transport circulation as revealed in model inter-comparisons and summarized in a recent review by Butchart (2014). Cohen *et al.* (2014) provide a potential explanation for the spread among different model recipes. Their idealized model studies showed that localized intense GW forces were largely compensated by reductions in forcing due to resolved Rossby waves, with almost no net influence on the transport circulation. They also found evidence for this compensation acting in full physics climate models (Cohen *et al.*, 2013). New theoretical developments have also provided a three-dimensional formulation for the residual circulation (Kinoshita and Sato,

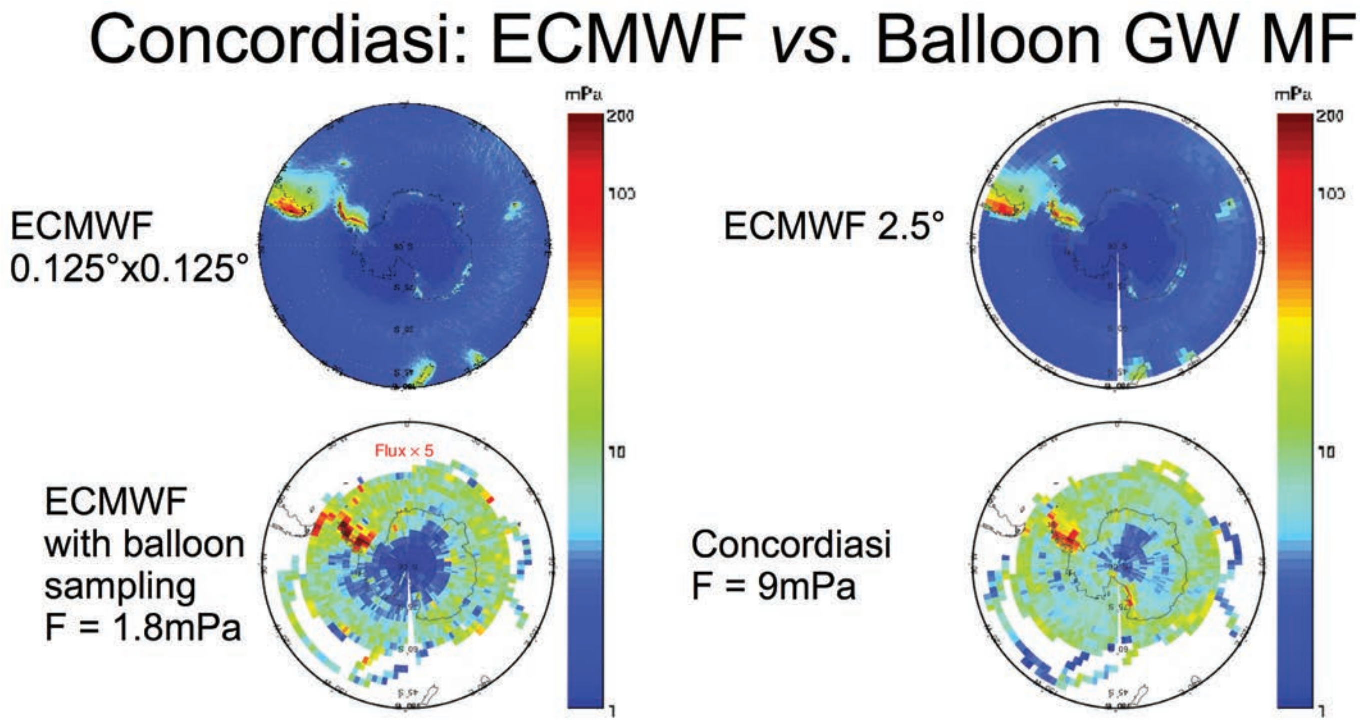


Figure 1: Comparison of momentum fluxes at 20km altitude from ECMWF analysis and Concordiasi superpressure balloon measurements from September 2009-January 2010. (a) ECMWF at native resolution, (b) 2.5° Concordiasi-like resolution, (c) and with the space/time balloon sampling taken into account, multiplied by 5x. (d) GW momentum fluxes inferred from the Concordiasi balloon campaign. The spatial distribution of GW fluxes agree well (except over Antarctica), but the ECMWF fluxes are underestimated by a factor of five, essentially due to the limited resolution of the ECMWF model. [Jewtoukoff *et al.*, 2015]

2013a,b). Small-scale GW forcing is generally zonally asymmetric, and the new three-dimensional form of the residual circulation can describe the zonally asymmetric response (Sato *et al.*, 2013).

We have summarized only a sample of new developments related to GWs in the recent literature here, highlighting a few recent results from researchers active in the SPARC Gravity Wave Activity, and choosing a focus on stratosphere-troposphere connections and their role in climate. Many other GW studies can be found in the literature that we have not covered here, and many new developments are underway. Just as planetary waves were a major focus of research in the mid-20th century as researchers began to model the global atmospheric circulation, today's global models have begun to directly simulate portions of the GW spectrum. The resulting studies of non-linear dynamical interactions between waves of all scales place GW dynamics at the centre of a 'new scale of interest' for modelling the global circulation.

Acknowledgements

The International Space Science Institute (ISSI) provided support to the group for 2013 and 2014 meetings in Bern, Switzerland, where many of the results described here were discussed. The authors would like to thank the participants in those ISSI meetings and those who contributed input for this article: Julio Bacmeister, Andrew Bushell, Naftali Cohen, Stephanie Evan, Marvin Geller, Albert Hertzog, Yoshio Kawatani, David Long, François Lott, Elisa Manzini, Charles McLandress, Peter Preusse, Manuel Pulido, Corwin Wright, and Nedjeljka Žagar.

References

Alexander, M.J. and A.W. Grimsdell, 2013: Seasonal cycle of orographic gravity wave occurrence above small islands in the Southern Hemisphere: Implications for effects on general circulation, *J. Geophys. Res.*, **118**, doi:10.1002/2013JD020526.

Choi, H.-J. and H.-Y.Chun, 2013: Effects of Convective Gravity Wave Drag in the Southern Hemisphere Winter Stratosphere, *J. Atmos. Sci.*, **70**, 2120–2136, doi: 10.1175/JAS-D-12-0238.1.

Cohen, N.Y., E.P. Gerber, and O. Bühler, 2014: What Drives the Brewer–Dobson Circulation?, *J. Atmos. Sci.*, **71**, 3837–3855. doi: 10.1175/JAS-D-14-0021.1.

Cohen, N.Y., E.P. Gerber, and O. Bühler, 2013: Compensation between resolved and unresolved wave driving in the stratosphere: Implications for downward control, *J. Atmos. Sci.*, **70**, 3780–3798, doi: 10.1175/JAS-D-12-0346.1

Eckermann, S.D., 2011: Explicitly Stochastic Parameterization of Nonorographic Gravity Wave Drag, *J. Atmos. Sci.*, **68**, 1749–1765, doi: 10.1175/2011JAS3684.1.

Ern, M., *et al.*, 2011: Implications for atmospheric dynamics derived from global observations of gravity wave momentum flux in stratosphere and mesosphere, *J. Geophys. Res.*, **116**, D19107, doi:10.1029/2011JD015821.

Ern, M., *et al.*, 2014: Interaction of gravity waves with the QBO: A satellite perspective, *J. Geophys. Res. Atmos.*, **119**, 2329-2355, doi:10.1002/2013JD020731.

France, J.A., *et al.*, 2012: HIRDLS observations of the gravity wave-driven elevated stratopause in 2006, *J. Geophys. Res.*, **117**, D20, doi:10.1029/2012JD017958.

Geller, M.A., *et al.*, 2013: A Comparison between Gravity Wave Momentum Fluxes in Observations and Climate Models, *J. Clim.*, **26**, 6383–6405, doi: 10.1175/JCLI-D-12-00545.1.

Hendricks, E.A., *et al.*, 2014: What Is the Source of the Stratospheric Gravity Wave Belt in Austral Winter?, *J. Atmos. Sci.*, **71**, 1583–1592, doi: 10.1175/JAS-D-13-0332.1.

Hertzog A., *et al.*, 2008: Estimation of gravity-wave momentum fluxes and phase speeds from long-duration stratospheric balloon flights. Part 2: Results from the Vorcore campaign in Antarctica, *J. Atmos. Sci.*, **65**, 3056–3070, 10.1175/2008JAS2710.1.

Hertzog, A., M.J. Alexander, and R. Plougonven, 2012: On the intermittency of gravity wave momentum flux in the stratosphere, *J. Atmos. Sci.*, **69**, 3433-3448, doi: 10.1175/JAS-D-12-09.1.

Hoffmann, L., X. Xue, and M.J. Alexander, 2013: A global view of stratospheric gravity wave hotspots located with Atmospheric Infrared Sounder Observations, *J. Geophys. Res.*, **118**, doi: 10.1029/2012JD018658.

Jewtoukoff, V., R. Plougonven, and A. Hertzog, 2013: Gravity waves generated by deep tropical convection: Estimates from balloon observations and mesoscale simulations, *J. Geophys. Res.*, **118**, doi: 10.1002/jgrd.50781.

Jewtoukoff V., *et al.*, 2015: Gravity waves in the Southern Hemisphere derived from balloon observations and the ECMWF analyses, *J. Atmos. Sci.*, (in revision).

Kalisch, S., *et al.*, 2014: Differences in gravity wave drag between realistic oblique and assumed vertical propagation, *J. Geophys. Res.*, **119**, 10,081–10,099, doi: 10.1002/2014JD021779.

Kawatani, Y.S., *et al.*, 2010: The Roles of Equatorial Trapped Waves and Internal Inertia–Gravity Waves in Driving the Quasi-Biennial Oscillation. Part I: Zonal Mean Wave Forcing, *J. Atmos. Sci.*, **67**, 963–980, doi: 10.1175/2009JAS3222.1.

Kawatani, Y., and K. Hamilton, 2013: Weakened stratospheric Quasibiennial Oscillation driven by increased tropical mean upwelling, *Nature*, **497**, 478-481, doi: 10.1038/nature12140.

Kim Y.-H., A.C. Bushell, D.R. Jackson, and H.-Y. Chun, 2013: Impacts of introducing a convective gravity-wave parameterization upon the QBO in the Met Office Unified Model, *Geophys. Res. Lett.*, **40**, 1873–1877, doi: 10.1002/grl.50353.

Kinoshita, T., and K. Sato, 2013a: A formulation of unified three-dimensional wave activity flux of inertia-gravity waves and Rossby waves, *J. Atmos. Sci.*, **70**, 1603-1615, doi:10.1175/JAS-D-12-0138.1.

Kinoshita, T., and K. Sato, 2013b: A formulation of three-dimensional residual mean flow applicable both to inertia-gravity waves and to Rossby waves, *J. Atmos. Sci.*, **70**, 1577-1602, doi: 101175/JAS-D-12-0137.1.

Kinoshita, T., and K. Sato, 2014: A formulation of three-dimensional residual mean flow and wave activity flux applicable to equatorial waves, *J. Atmos. Sci.*, **71**, 3427-3438, doi: 10.1175/JAS-D-13-0161.1.

Lott, F., L. Guez, and P. Maury, 2012: A stochastic parameterization of non-orographic gravity waves: Formalism and impact on the equatorial stratosphere, Geophys. *Res. Lett.*, **39**, L06807, doi: 10.1029/2012GL051001.

McLandress C., T.G. Shepherd, S. Polavarapu, and S.R. Beagley, 2012: Is Missing Orographic Gravity Wave Drag near 60°S the Cause of the Stratospheric Zonal Wind Biases in Chemistry–Climate Models?, *J. Atmos. Sci.*, **69**, 802–818, doi: 10.1175/JAS-D-11-0159.1.

Plougonven, R., and F. Zhang, 2014: Internal gravity waves from atmospheric jets and fronts, *Rev. Geophys.*, **52**, 33–76, doi: 10.1002/2012RG000419.

Preusse, P., *et al*., 2014: Characteristics of gravity waves resolved by ECMWF, *Atmos. Chem. Phys.*, **14**, 10483-10508, doi: 10.5194/acp-14-10483-2014.

Pulido, M. and J. Thuburn, 2005: Gravity-wave drag estimation from global analyses using variational data assimilation principles. I: Theory and implementation, *Q. J. R. Meteorol. Soc.*, **131**, 1821–1840, doi: 10.1256/qj.04.116.

Pulido, M., 2014: A Simple Technique to Infer the Missing Gravity Wave Drag in the Middle Atmosphere Using a General Circulation Model: Potential Vorticity Budget, *J. Atmos. Sci.*, **71**, 683-696, doi: 10.1175/JAS-D-13-0198.1.

Rabier, F., *et al.*, 2013: The Concordiasi Field Experiment over Antarctica: First Results from Innovative Atmospheric Measurements, *Bull. Amer. Meteor. Soc.*, **94**, ES17–ES20, doi:10.1175/BAMS-D-12-00005.1.

Richter, J.H., F. Sassi, and R.R. Garcia, 2010: Toward a physically based gravity wave source parameterization in a general circulation model, *J. Atmos. Sci.*, **67**, 136-156, doi: 10.1175/2009JAS3112.1.

Richter, J.H., A. Solomon, and J.T. Bacmeister, 2014a: On the simulation of the quasi-biennial oscillation in the Community Atmosphere Model, version 5, *J. Geophys. Res.* **119**, 3045-3062, doi: 10.1002/2013JD021122.

Richter, J.H., A. Solomon, and J.T. Bacmeister, 2014b: Effects of Vertical Resolution and Non-Orographic Gravity Wave Drag On the Simulated Climate in the Community Atmosphere Model, Version 5, *J. Adv. Model. Earth Sys.*, **6**, 357-383, doi: 10.1002/2013MS000303.

Sato, K., S. Tateno, S. Watanabe, and Y. Kawatani, 2012: Gravity Wave Characteristics in the Southern Hemisphere Revealed by a High-Resolution Middle-Atmosphere General Circulation Model, *J. Atmos. Sci.*, **69**, 1378–1396, doi: 10.1175/JAS-D-11-0101.1.

Sato, K., T. Kinoshita, and K. Okamoto, 2013: A new method to estimate three-dimensional residual mean circulation in the middle atmosphere and its application to gravity-wave resolving general circulation model data, *J. Atmos. Sci.*, **70**, 3756–3779, doi: 10.1175/JAS-D-12-0352.1.

Sato, K., *et al.*, 2014: Program of the Antarctic Syowa MST/IS Radar (PANSY), *J. Atmos. Solar-Terr. Phys.*, **118**, 2-15, doi: 10.1016/j.jastp.2013.08.022.

Scaife, A. A., *et al.*, 2014: Skillful long-range prediction of European and North American winters, *Geophys. Res. Lett.*, **41**, 2514–2519, doi: 10.1002/2014GL059637.

Schirber, S., E. Manzini, and M.J. Alexander, 2014a: A convection based gravity wave parameterization in a general circulation model: Implementation and improvements on the QBO, *J. Adv. Model. Earth Syst.*, **6**, 264–279, doi: 10.1002/2013MS000286.

Schirber, S., E. Manzini, T. Krismer, and M. Giorgetta, 2014b: The Quasi-Biennial Oscillation in a warmer climate: Sensitivity to different gravity wave parameterizations, *Clim. Dyn.*, doi: 10.1007/s00382-014-2314-2.

Sigmond, M., and J.F. Scinocca, 2010: The influence of basic state on the Northern Hemisphere circulation response to climate change, *J. Clim.*, **23**, 1434-1446, doi: 10.1175/2009JCL13167.1.

Sigmond, M., J.F. Scinocca, V.V. Kharin, T.G. Shepherd, 2013: Enhanced seasonal forecast skill following stratospheric sudden warmings, *Nature Geosci.*, **6**, 98-102, doi: 10.1038/ngeo1698.

Song, I.-S., and H.-Y. Chun, 2008: Lagrangian spectral parameterization of gravity wave drag induced by cumulus convection, *J. Atmos. Sci.*, **65**, 1204-1224, doi: 10.1175/2007JAS2369.1.

Tomikawa, Y., *et al.*, 2012: Growth of planetary waves and the formation of an elevated stratopause after a major stratospheric sudden warming in a T213L256 GCM, *J. Geophys. Res.*, **117**, doi: 10.1029/2011JD017243.

Wright, C.J., *et al.*, 2010: High Resolution Dynamics Limb Sounder measurements of gravity wave activity in the 2006 Arctic stratosphere, *J. Geophys. Res.*, **115**, doi: 10.1029/2009JD011858.

Wright, C.J., S.M. Osprey, and J.C. Gille, 2013: Global observations of gravity wave intermittency and its impact on the observed momentum flux morphology, *J. Geophys. Res. Atmos.*, **118**, 10,980–10,993, doi: 10.1002/jgrd.50869.

Vincent, R.A., and Hertzog, A., 2014: The response of superpressure balloons to gravity wave motions, *Atmos. Meas. Tech.*, **7**, 1043-1055, doi: 10.5194/amt-7-1043-2014.

Yasuda, Y., K. Sato, and N. Sugimoto, 2014a: A theoretical study on the spontaneous radiation of inertia-gravity waves using the renormalization group method. Part I: Derivation of the renormalization group equations, *J. Atmos. Sci.*, doi: 10.1175/JAS-D-13-0370.1.

Yasuda, Y., K. Sato, and N. Sugimoto, 2014b: A theoretical study on the spontaneous radiation of inertia-gravity waves using the renormalization group method. Part II: Verification of the theoretical equations by numerical simulation, *J. Atmos. Sci.*, doi: 10.1175/JAS-D-13-0371.1.

Report on the 2nd Joint SOLARIS-HEPPA Meeting, 5-9 May 2014, Baden-Baden, Germany

Katja Matthes[1,2], Bernd Funke[3], and Gabriele Stiller[4].

[1]GEOMAR Helmholtz Centre for Ocean Research Kiel, Germany, **kmatthes@geomar.de**, [2]Christian-Albrechts Universität zu Kiel, Kiel, Germany, [3]Instituto de Astrofísica de Andalucía, CSIC, Granada, Spain, [4]Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany.

The 2nd SOLARIS-HEPPA (SOLAR Influences for SPARC) workshop was held together with the 5th HEPPA (High Energy Particle Precipitation in the Atmosphere) workshop from 5-9 May 2014 in Baden-Baden, Germany, organised by the Karlsruhe Institute of Technology (KIT) (**http://www.imk-asf.kit.edu/english/HEPPA_SOLARIS_2014.php**). 72 participants from 13 countries attended the five-day workshop to discuss the newest advances in understanding the influences of solar radiation and energetic particle precipitation on space weather, the atmosphere, and climate. This was the second HEPPA workshop since 2012 that has been organized in conjunction with the SPARC SOLARIS-HEPPA community. The workshop was focused on several topics: 1) variability of energetic particle precipitation and solar irradiance; 2) uncertainties in their measurements; 3) observed and modelled impacts of solar forcing on the atmosphere (thermosphere to surface) and climate; and 4) predictions for future scenarios under a weakening sun.

The first three days were a mixture of invited overview talks in plenary and extended poster sessions (with a total of 48 posters). Each of the poster sessions was introduced by one-slide summaries in plenary to give an overview of the poster contents.

After a welcome from the local organizing committee (Gabi Stiller), **Harlan Spence** summarized the history of the radiation belt discovery and our current understanding of it. He then gave an overview of NASA's recently launched (summer 2012) Van Allen Probes mission to investigate energetic particles and presented some first exciting results. He finished off by discussing some results from WACCM showing the model's response to a solar proton event (SPE). Although the modelled odd nitrogen response agrees well with satellite observations in the stratosphere, WACCM could not explain the observed surface nitrate spikes at Summit, Greenland, raising questions about the use of nitrate deposition measurements as a proxy for SPEs.

Mark Clilverd talked about challenges and problems in measuring energetic electron precipitation (EEP) into the atmosphere. First, he highlighted the importance of EEP for atmospheric chemistry during winter (particularly for HO_x and NO_x) due to its impact on the ozone balance between 30-80km and on timescales of relevance for regional climate. He continued by discussing the difficulties of measuring precipitating electron fluxes with current satellite instruments. The main problem, apart from sensitivity issues, is the limited pitch-angle coverage of the observed electrons in the bounce loss cone, which leads to different responses under weak (*i.e.*, quiescent) and strong (*i.e.*, geomagnetic storm) diffusion conditions. Such observations agree well with ground-based observations during episodes of high electron fluxes, but tend to overestimate weak fluxes particularly at high energies.

Thierry Dudok de Witt reported on the current status of the controversy with solar irradiance measurements and discussed whether the current solar cycles are unusual. The Mg-II index, a measure for solar activity, should not be used for the last solar cycle as it is very different from other indices, such as total solar irradiance (TSI), sunspot number, radio flux (10.7cm and 30cm), or the intensity of the Lyman-α line. The present solar cycle is weak but not unusual and is similar to the one from 1914-1918. The spectral solar irradiance has changed since the last solar cycle, with lower intensity in the extreme ultraviolet (EUV). Satellite instruments disagree particularly in the ultraviolet (UV), at wavelengths between 200-295nm, and might contain uncorrected degradation in this range (especially observations from the SORCE mission).

Natalie Krivova also discussed the characteristics of the current solar cycle (number 24) and the difficulty of predicting the evolution of future solar cycles. She concluded that the probability of another grand minimum in solar activity occurring within the next 30-40 years is lower than 10%. However, the chance of such an occurrence within the next 200 years is about 40-50%, or in other words, the next grand episode is just as likely to be a grand maximum as a grand minimum. Solar cycle 24 has been the weakest of the six most recent and well-observed cycles. Overall, it is the seventh weakest of the past 28 cycles spanning the last 300 years, and is just above average compared to Holocene solar activity, with average irradiance properties.

Martyn Mlynczak reviewed the Sounding of the Atmosphere using Broadband Emission Radiometry (SABER) instrument on-board NASA's Thermosphere Ionosphere Mesosphere Energetics Dynamics (TIMED) mission and showed results indicating a signature of solar variability on the temperature, composition, and energy balance of the mesosphere and thermosphere. SABER data reveal long- and short-term variability in the energy budget of the thermosphere and mesosphere, both of which are driven by changes in solar EUV and geomagnetic conditions. In the mesosphere there is an inverse relationship between the solar cycle and hydrogen and ozone. The SABER data are now freely available online (see **http://saber.gats-inc.com/data.php**).

Monika Anderson talked about the effects of radiation belt electrons on mesospheric hydroxyl (OH) and ozone. The analysis of OH data from the Microwave Limb Sounder (MLS) together with electron count rate observations from Medium-Energy Proton and Electron Detector (MEPED) provide clear evidence of the connection between precipitating radiation belt electrons and mesospheric OH at auroral latitudes. Comparisons with mesospheric ozone observations from satellite instruments indicate that the precipitation-induced increase in OH is typically accompanied by decrease in ozone at altitudes between 60-80km.

Dan Marsh reported on the progress made in the detection of solar cycle signals in the lower atmosphere since the review paper of Gray *et al.* (2010). Significant advances have been made both in terms of understanding and modelling solar signals in the troposphere through the inclusion of the stratosphere, chemistry, and ocean coupling into models. The agreement between observed and modelled responses to solar and geomagnetic forcing in the stratosphere and mesosphere is better understood than in the troposphere. The IPCC consensus is that the solar influence on global mean surface climate is small compared to anthropogenic forcing, however, the solar influence is larger at the regional scale. A detailed understanding of tropospheric responses and mechanisms is still needed.

Marko Laine reviewed mathematical and statistical uncertainty quantification methods for large-scale models used in atmospheric and climate research. Typically, such methods are based on Monte Carlo simulations, either using parallel ensembles of model runs or sequential algorithms such as Markov chain Monte Carlo analyses. As a typical application, he discussed the parameter sensitivity

Figure 2: Group Picture of the SOLARIS-HEPPA Meeting in Baden-Baden, Germany. Photo: Gabriele Stiller (KIT).

analysis for an atmospheric chemical transport model FinROSE, and for the Sodankylä Ion Chemistry model.

Jeff Knight showed the influence of solar variability on past and present North Atlantic climate. In particular, he discussed the response of the North Atlantic Oscillation to the solar cycle, which lags solar cycle peaks by a few years in observations. Atmosphere-ocean coupling seems to be responsible for this lag as demonstrated by a simple model study. He also showed further evidence for the 'top-down' stratospheric mechanism.

Eugene Rozanov discussed the effects of solar irradiance (in the UV, visible (VIS), and near infrared (NIR) ranges) and particle (magnetospheric/auroral and radiation belt electrons, solar protons, and galactic cosmic rays) variability on tropospheric climate in observational and modelling studies. He showed that solar and particle effects on tropospheric climate are similar in magnitude and should be taken into account in climate models. However, the efficacy of the 'top-down' mechanism varies significantly from model to model.

Amanda Maycock presented possible implications of a future grand solar minimum for surface climate. She reviewed recent modelling studies that show a consistent small impact of a future grand solar minimum on global warming, in particular on surface air temperatures. However, regional effects might be larger and non-negligible.

Outstanding Questions

At the end of the third day, **Katja Matthes** and **Bernd Funke** summarized the principal questions facing the SOLARIS-HEPPA community. Questions related to solar forcing are: How accurate are spectral solar irradiance observations? How accurate are models and how can they be improved? How much does the TSI background vary on longer timescales? How is atmospheric ionization by energetic particles distributed in the atmosphere? What is the role of medium energetic electrons? Furthermore, it is important to decide on the most reliable solar forcing dataset and a reasonable future scenario to be used in the upcoming Coupled Model Intercomparison Project – 6 (CMIP6) assessment.

Open questions with respect to the mechanisms and climate impacts of solar radiation and precipitating particles are: What are the regional impacts of solar variability? What are the key mechanisms for the transfer of the solar signal to the surface? What is the relative importance of solar irradiance versus energetic particle effects? What is the role of the ocean (lagged response)? What would be the climate impact for different future solar variability scenarios? Are the physical processes involved in solar signal propagation reasonably well represented in climate models? For example, there is a large model spread regarding the representation of the 'top-down' mechanism and the polar winter descent of EPP-NO_x. How can the solar signal be reliably extracted and separated from other sources of variability, both from observational records and model estimates?

For the remainder of the meeting, these questions were used as the basis to discuss possible activities, future modelling studies, process-oriented studies, and also the possibility of comparing different (non-) linear analysis methods.

Awards

Rémi Thiéblemont, a Postdoc at the GEOMAR Helmholtz Centre for Ocean Research Kiel in Germany, was nominated for the IAGA Young Scientist Award in recognition of the high quality of his poster presentation 'North Atlantic Surface Response to the 11-Year Solar Cycle'. If Rémi is selected by the International Association of Geomagnetism and Aeronomy (IAGA), he will receive the registration fee to attend the next International Union of Geodesy and Geophysics (IUGG) conference in Prague, Czech Republic, being held in July 2015.

Working group meetings

The fourth day of the meeting was dedicated to an overview of ongoing international activities. **Katja Matthes** and **Bernd Funke** gave an overview of SOLARIS-HEPPA work in 2014. The activity now has a joint website where all important information can be found (**http://solarisheppa.geomar.de/**). A number of publications are currently underway to finalize the HEPPA-II intercomparison (in preparation) and several covering an intercomparison of solar signals in CMIP5 simulations (SolarMIP; Mitchell et al., 2014; Misios et al., 2014; Hood et al., 2014) and related investigations (Thiéblemont et al., 2014) are in the publishing process. In addition, several SOLARIS-HEPPA members are involved in producing an undergraduate-level textbook describing the solar influence on climate. The book consists of a series of short topical chapters and is being coordinated by the EU-COST network TOSCA ('Towards a more complete assessment of the impact of solar variability on the Earth's climate'; **www.cost-tosca.eu**). There was a special SOLARIS-HEPPA session at the 2014 EGU in Vienna: 'CL5.12: Solar Influence on the Middle Atmosphere and Dynamical Coupling to the Troposphere and the Ocean' (Convener: Katja Matthes, Co-Convener: Margit Haberreiter). The next step will be the start of a joint SOLARIS-HEPPA coordinated evaluation of the solar cycle signal in the SPARC Chemistry Climate Model Initiative (CCMI) hindcast simulations and satellite observations, including an assessment of analysis tools (multiple regressions) and a quantification of individual contributions to the solar signal.

After the SOLARIS-HEPPA activity report, a few related projects were presented. **Margit Haberreiter** reported on the status of the SOLID project - an EU-FP7 Project entitled 'First European Comprehensive Solar Irradiance Data Exploitation'. **Annika Seppälä** reported on the new SCOSTEP/VarSITI ROSMIC ('Role of the Sun and the Middle Atmosphere/thermosphere/ionosphere in Climate') programme, which started in 2014 and will run through 2018. **Dan Marsh** gave an update on the ISSI Project 'Quantifying hemispheric differences in particle forcing effects on stratospheric ozone', and **Irina Mironova** introduced her ISSI Project 'Specification of Ionization Sources Affecting Atmospheric Processes'. **Thierry Dudok de Witt** reported on TOSCA, and **Cora Randall** introduced the newly launched RAISE ('Response of the Atmosphere to Impulsive Solar Events') project funded by NASA. These presentations were followed by a discussion about possible synergies and collaborations.

Later in the day, ongoing SPARC SOLARIS-HEPPA activities were presented in more detail. Presentations focused on the latest HEPPA-II model-measurement intercomparison results (**Bernd Funke**), an intercomparison of trace gas observations during the 2008/2009 northern hemisphere winter (**Kristell Pérot**), a comparison of nitric oxide measurements in the mesosphere and lower thermosphere (MLT) from the ACE, MIPAS, Odin/SMR, and SCIAMACHY satellites (**Stefan Bender**), 3D chemistry transport model studies on MLT NO_x from energetic particles and photoionization (**Holger Nieder**), the set-up and early results from tracer experiments looking at sudden stratospheric warmings in the winter of 2008/2009 (**Miriam Sinnhuber**), as well as two presentations on the solar signals in Coupled Model Intercomparison Project-5 (CMIP5) simulations, one about the 'stratospheric pathway' (**Katja Matthes**) and the other about effects of atmosphere-ocean coupling (**Stergios Misios**).

The fifth and last day of the workshop was dedicated to a working group meeting, with breakout groups for specific SOLARIS and HEPPA activities as well as a final joint session with reports from the breakout groups and discussion of future SOLARIS-HEPPA activities. In both breakout groups the current status of publications to be finalized in the next six months was discussed.

The next SPARC SOLARIS-HEPPA working group meeting is planned for autumn 2015 in Boulder, Colorado, USA. The next joint HEPPA/SOLARIS workshop will be held in early 2016 in Helsinki, Finland.

Acknowledgements

We would like to thank WCRP/SPARC for its support, as well as KIT/Karlsruhe, SCOSTEP/VarSITI, IAMAS, IAGA, and IUGG. We especially thank the local organizing committee for an excellent venue and organisation of the meeting.

We dedicate this article to the memory of Joachim ("Jo") Urban, who passed away in August 2014, at the age of only 49 from a heart attack. Jo was responsible for the operational Odin/SMR level-2 processing in Sweden and, in particular, his contributions to the assessment of the atmospheric response to energetic particles had a far-reaching impact on the work of SOLARIS-HEPPA. We have lost a good friend and valuable member of the SOLARIS-HEPPA activity.

References

Hood, L., *et al.*, 2014: Solar Signals in CMIP-5 Simulations: The Ozone Response, to be submitted to *Q. J. Roy. Met. Soc.*

Misios, S., *et al.*, 2014: Solar Signals in CMIP-5 Simulations: Effects of Atmosphere-Ocean Coupling, to be submitted to *Q. J. Roy. Met. Soc.*

Mitchell, D., *et al.*, 2014: Solar Signals in CMIP-5 Simulations: The Stratospheric Pathway, submitted to *Q. J. Roy. Met. Soc*.

Seppälä, A., K. Matthes, C. Randall, and I. Mironova, 2014: What is the solar influence on climate? Overview of activities during CAWSES-II, special issue of *Progr. Earth and Planet. Sci.*, accepted.

Thiéblemont, R., *et al.*, 2014:, Solar Forcing Synchronizes Decadal North Atlantic Climate Variability, submitted to *Nat. Commun.*

Report on the MOZAIC–IAGOS Scientific Symposium on Atmospheric Composition Observations by Commercial Aircraft: 20th Anniversary. 12-15 May 2014, Toulouse, France

Valérie Thouret[1] and Andreas Petzold[2].

[1]Laboratoire d'Aérologie, CNRS and Université Paul Sabatier, Toulouse, France, **valerie.thouret@aero.obs-mip.fr**
[2]Research Center Jülich.

The first MOZAIC-IAGOS Symposium on 'Atmospheric Composition Observations by Commercial Aircraft' was held from 12-15 May 2014 at Airbus and Météo-France, Toulouse, France. It was dedicated to a celebration of 20 years of MOZAIC (Measurement of Ozone and Water Vapour by Airbus In-service Aircraft) observations and to explore future possibilities within the ongoing IAGOS (In-service Aircraft for a Global Observing System) programme. In total there were 150 participants from Europe, USA, China, Japan, and India. The programme and other relevant information can be found on the workshop homepage at **http://www.meteo.fr/cic/meetings/2014/MOZAIC-IAGOS**, while the presentations are available from the IAGOS web site: **http://www.iagos.fr**.

Celebration of 20 years of MOZAIC

Climate change, air quality, and the oxidizing capacity of the atmosphere are major issues that require detailed, long-term observations of atmospheric chemical composition on a global scale. For 20 years MOZAIC and its successor IAGOS have successfully harnessed the potential of in-service aircraft to respond to these needs.

Uncertainties in our current knowledge result from the complexity of feedback mechanisms in the climate system, for example, the amplification of the CO_2-induced greenhouse effect of water vapour (Lacis *et al.*, 2010); the effect of aerosol on cloud formation and cloud microphysics (Clarke and Kapustin, 2010; Schwartz *et al.*, 2010); the role of deep convection in transporting gases and aerosol into the upper troposphere/lower stratosphere (UTLS), in particular over South-East Asia (in the Asian Monsoon), and its behaviour within a changing climate (Randel *et al.*, 2010); or the modification of biological cycles by climate change (Mahowald, 2011), including feedbacks through biogeochemical and bio-geophysical processes that alter the sources and sinks of CH_4 and CO_2 (Friedlingstein *et al.*, 2006). These uncertainties, in turn, imply large uncertainty in predicting the future climate, especially at regional scales (Lenton, 2011).

The atmospheric greenhouse effect is not confined to the lower atmosphere, but is largely driven by changes in the UTLS (Riese *et al.* 2012). For instance, the small increase of water vapour observed in the stratosphere (increasing ~0.8ppm from 1980-2010) is likely responsible for 25% of the total anthropogenic greenhouse effect (Solomon *et al.*, 2010). Climate change also influences air quality by modifying atmospheric transport and weather patterns (Min *et al.*, 2011), with impacts on air quality in Europe and other regions of the world due to long-range transport of pollutants, ozone, and aerosol from developing economies (Monks *et al.*, 2009).

IAGOS aims to fill the gap in the global *in situ* observing system by collecting crucial data throughout the troposphere and in the critical UTLS region, including regions poorly or never sampled by other means, at global scales and at high temporal and spatial resolutions. IAGOS perfectly complements ground-based networks and observations from satellite instruments. IAGOS builds on 20 years of scientific and technological expertise gained in the MOZAIC and CARIBIC (Civil Aircraft for the Regular Investigation of the Atmosphere Based on an Instrument Container) research projects.

The IAGOS programme involves research centres, universities, national weather services, airline operators, and the aviation industry. Participating airlines from different continents ensure global coverage of the network and in 2014 the fleet consisted of five IAGOS-CORE (Air-France, Lufthansa, Cathay Pacific, China Airlines, and Iberia), one IAGOS-CARIBIC (Lufthansa), and one MOZAIC (Lufthansa) aircraft. The emerging global-scale network is illustrated in **Figure 4**. Destinations covered by CARIBIC are globally distributed, with the majority of flights heading to North America and the Far East, as well as a few to South Africa and South America. A map of recent destinations is accessible at **www.caribic-atmospheric.com**.

The celebration of the 20th anniversary of MOZAIC was held at Airbus on 12 May and gathered about 150 attendees representing historical and current partners of the programme including airlines (Air France, Lufthansa, China Airlines, Cathay Pacific) and Airbus, the recently founded non-profit international association (IAGOS-AISBL), and the worldwide scientific community, along with funding agencies, highlighting their strong commitment to advancing climate research. Long-term European support was confirmed by **Máire Geoghegan-Quinn**, European Commissioner for Research, Innovation, and Science (available on video at **http://www.iagos.fr**). She recalled that IAGOS entered the ESFRI (European Strategy Forum on Research Infrastructures) Roadmap for new research infrastructures in 2006 and in 2012 IAGOS was listed as one of the ESFRI Success Stories. In a recent report from the expert group assessing projects on the ESFRI Roadmap (published in 2013), IAGOS is listed among those ready for implementation by 2015. She confirmed the role IAGOS is playing and must keep playing in the European landscape for global-scale atmospheric monitoring.

This celebration day also included keynote scientific presentations:

Guy Brasseur summarized the science achievement of MOZAIC. His presentation highlighted the significant contributions of MOZAIC data to studies focusing on the UTLS region, in particular on stratosphere-troposphere exchange and ozone, as well as studies trying to understand background water vapour levels and trends. He also emphasized the growing importance of MOZAIC data for the validation of atmospheric models and satellite retrievals, and for global air quality studies. A full list of publications making extensive use of MOZAIC is available at **http://www.iagos.fr.**

Leonard Barrie gave an overview on the role of IAGOS and other European infrastructures in global air chemistry research, completed by **Gelsomina Pappalardo** who presented the visions for a future integrated global atmospheric composition observations system in Europe and worldwide.

Andreas Volz-Thomas focused on the history and future prospects of using commercial passenger aircraft as measurement platforms for atmospheric observations. IAGOS is designed for global-scale coverage and a lifetime of at least 20 years. The infrastructure will provide long-term, regular, accurate, and spatially resolved *in situ* atmospheric observations of atmospheric chemical composition, aerosol number concentration, aerosol size, and cloud droplet number concentration to scientists and policy-makers. IAGOS will achieve a level of data quality that other measurement methods are unable to attain, deploying identical systems with identical and regular quality assessment procedures, including calibration against reference instruments based on GAW standard procedures. This input is essential for climate

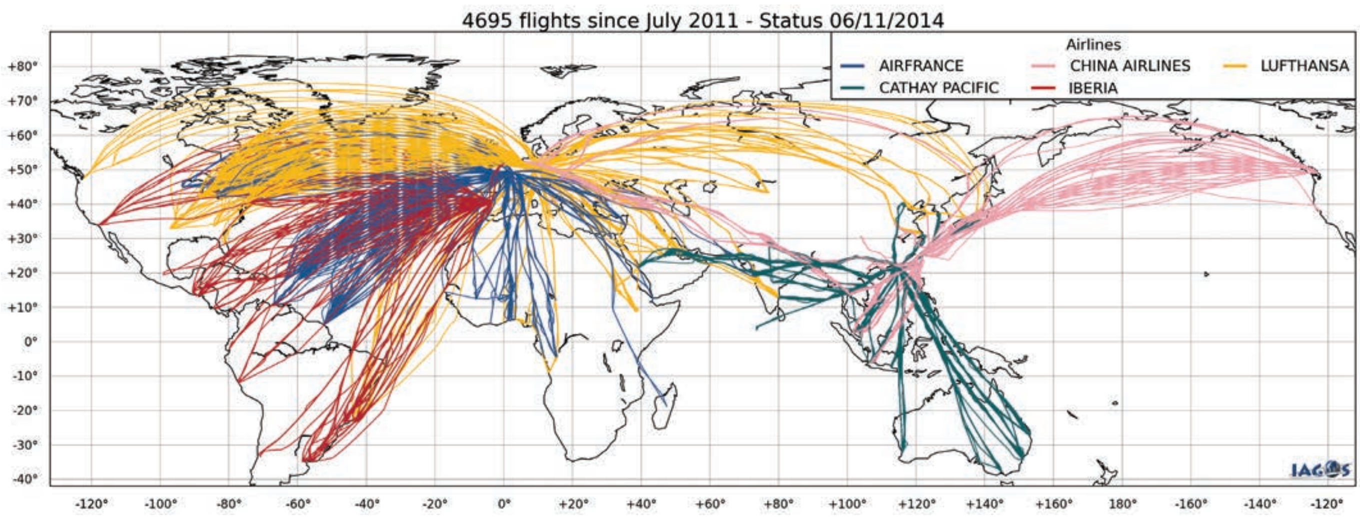


Figure 3: Map of the IAGOS flight tracks since July 2011, with thanks to the five participating airlines.

research, emissions monitoring, weather prediction, and air quality forecasting, including those made by the Copernicus Atmosphere Monitoring Service (a demonstration tool is detailed at **http://www.iagos.fr/macc**) and for the carbon cycle models employed for the verification of carbon dioxide emissions and Kyoto monitoring. Regional air quality models will assimilate the near real-time data to improve forecasts.

Scientific workshop – What are MOZAIC-IAGOS data used for?

The following two and a half days of the symposium were dedicated to scientific presentations, with about 80 participants at the 'Centre International de Conférence' at Météo-France. The main objectives were to further strengthen collaboration between the different communities involved in the programme and to foster development in research themes. It was also important to try to further understand the needs of data users both in terms of database functionality and measurement capacity. We received more than 70 abstracts and ended up having 45 talks and 20 posters. Each of the six sessions was introduced by an invited speaker who gave an overview of the topic and emphasized MOZAIC-IAGOS contributions to the question.

(1) Evaluation/Validation of Satellites and Surface Remote Sensing

Peter Van Velthoven presented a number of highlights to illustrate the promise IAGOS data hold for the future, for example, evaluating predictions made by Copernicus Atmosphere Monitoring Services. IAGOS data have been used to validate SCIAMACHY, MOPITT, and IASI carbon monoxide observations; IASI ozone; GOME-2 sulphur dioxide and bromine oxide observations; as well as FTS surface observations of carbon dioxide and methane. The variety of measurements collected on-board the IAGOS CARIBIC aircraft also allow evaluation of many different species in atmospheric chemistry models. The quasi-horizontal flight paths of IAGOS aircraft in the UTLS have also proven highly valuable for evaluating vertical transport processes in these models.

(2) Long-Range Transport of Air Pollutants

Kathy Law entitled her introductory talk 'Hemispheric Ozone: Current Understanding and Future Directions'. She synthesized the main findings of the HTAP (Hemispheric Transport of Air Pollutant) activities, as published in the 2010 report (available at **www.htap.org**). In particular, it was shown that 30% of the surface ozone response in a receptor region results from changes outside that region, which

Figure 4: Participants of the MOZAIC-IAGOS Symposium at Airbus, Toulouse

has strong implications for ozone trend assessments. In addition, long-range transport of trace gases also has significant implications for air quality management. She mentioned that the quasi-global spatial and temporal coverage of the MOZAIC-IAGOS data make them invaluable for further improving our understanding of ozone source attribution and trends. She also pointed out that one of the next challenges to address will be better determining local versus hemispheric controls as local emissions decrease and air quality thresholds are lowered. Contributions from the session confirmed how the MOZAIC-IAGOS data can be used address issues such as establishing the origin of ozone. For example, **Alicia Gressent** showed how ozone was produced downwind of lightning NO_x production regions over North America and North Atlantic (recently published in the Tellus-B MOZAIC special issue; Gressent *et al.*, 2014).

(3) Recent Technical Developments

Philippe Nédélec introduced the session by providing an overview of the history of MOZAIC instrumentation. **Christoph Gerbig** then highlighted the FP7 project IGAS (**www.igas-project.org**) which is focusing on new technology developments in the framework of IAGOS, including new measurement methods and improved quality assessment and quality check procedures to link with global networks. The suite of instruments operated on-board the IAGOS aircraft consists of one unit (Package 1), which measures ozone, water vapour, carbon monoxide, as well as cloud droplet number concentrations, and is deployed on every aircraft. A second unit (Package 2), targeting specific species and properties such as nitrogen-containing compounds, greenhouse gases, or aerosol particle properties, will be installed by early 2015. The fully equipped IAGOS instrument rack weighs approximately 120kg and is mounted in the bay of Airbus A340/A330 aircraft. Extensive evaluation studies of the on-board water vapour sensors (based on capacitive hygrometers) were presented by **Patrick Neis**. He pointed out the consistently high quality of data, even during the transition from MOZAIC to next-generation IAGOS humidity sensors.

Details about the extensive CARIBIC measurement techniques were provided by Brenninkmeijer *et al.* (2007) and the CARIBIC team (2007), and were presented by **Andreas Zahn**. In 2010 the CARIBIC container returned to operation aboard Lufthansa A340-600 aircraft, being deployed on four flights per month.

All data from IAGOS and its predecessor programmes are freely available to the scientific community on request via the IAGOS database, which is hosted by the French atmospheric data centre ETHER (a joint venture between the national research and space agency, CNRS and CNES, respectively). The database, presented and managed by **Damien Boulanger**, is accessible via **www.iagos.fr**.

(4) UTLS Chemical Composition and Trends

Bill Randel presented an overview of the key topics concerning UTLS composition, including large-scale transport and mixing, seasonal and interannual variability, monsoon circulations (especially the Asian summer monsoon), and impacts of deep convection. He presented results from a number of recent campaigns and highlighted the main findings related to the northern mid-latitude UTLS using data obtained from the extensive MOZAIC-IAGOS and CARIBIC-IAGOS databases (Thouret *et al.*, 2000; 2006; Schuck *et al.*, 2010; Baker et al., 2011).

Owen Cooper presented a recent review article about the global distribution and trends of tropospheric ozone (Cooper *et al.*, 2014). He also took the opportunity to present the new IGAC TOAR (Tropospheric Ozone Assessment Report) activity he is currently chairing. The objective of this report is to answer several basic questions, such as: Is ozone continuing to decline in countries with strong emission controls? To what extent is ozone increasing in developing countries? Thanks to its global coverage and consistent instrumentation over the past 20 years MOZAIC-IAGOS undoubtedly constitutes one of the most important data sets for this evaluation.

(5) Monitoring Atmospheric Composition, Climate and Air Quality

Vincent-Henri Peuch introduced the Copernicus Atmosphere Monitoring Service (CAMS). CAMS, previously known as GMES (Global Monitoring for Environment and Security), is a programme establishing a European capacity for Earth observation. CAMS addresses aspects relative to atmospheric composition by providing monitoring, forecast, or retrospective information about greenhouse gases, reactive gases, and aerosol at the global scale and (at higher resolution) over Europe. This service is based on a heritage of successive European Framework

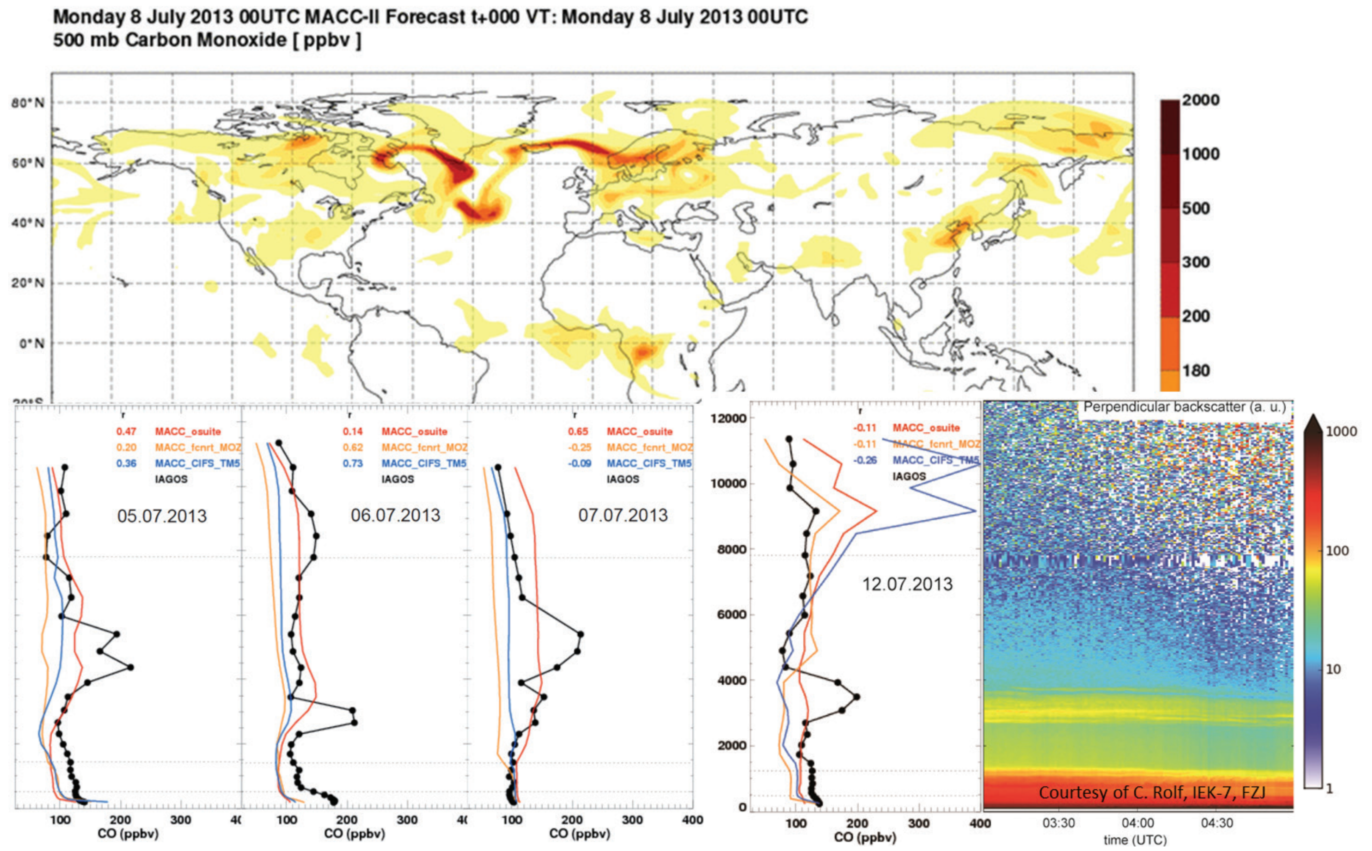


Figure 5: An example of the use of IAGOS data to monitor the impacts of Canadian biomass burning emissions on air quality forecasts over Europe. Top: CO mixing ratios (ppb) at 500hPa on 8 July 2013 at 00UTC as calculated by the MACC-II forecast model. Bottom left: vertical profiles of CO mixing ratios (ppb) recorded over Frankfurt airport (black line) compared to various runs of the MACC-II model (coloured lines) for four days in July 2013. Bottom right: time-altitude cross-section of aerosol derived from lidar measurements at Jülich (about 200km west of Frankfurt) on 12 July 2013, showing a layer with a high concentration of particles from 2-4km altitude, where IAGOS aircraft sampled a CO-enhanced layer with concentrations up to 200ppb.

Programme projects (GEMS, MACC, MACC-II), which have supported ambitious scientific and technical developments over the last decade. These projects have made routine use of MOZAIC-IAGOS data, which have been particularly useful for independent validation of the products developed in the projects. Their potential for use in data assimilation (either as an 'anchor' for bias-correction schemes or in 'active' assimilation) has also been explored. The future deployment of a larger fleet of IAGOS-equipped aircraft measuring a wider variety of atmospheric constituents is a very important perspective for CAMS. The near real-time processing and data transmission capabilities of IAGOS will also make it possible to include the corresponding data stream into operational processing, similar to the aircraft meteorological data relay that is used for numerical weather prediction. His talk and those from participants in this session showed some of the insight and experience gained using IAGOS data in the on-going MACC-II project, highlighting in particular the usefulness of *in situ* observations during significant large-scale pollution episodes (*e.g.* biomass burning from Siberia and Canada in 2013, as seen in **Figure 5**).

(6) Water Vapour and Clouds

To open the 'water vapour and clouds' session, **Peter Spichtinger** provided a synopsis of current knowledge about cirrus cloud formation and their properties. Cirrus clouds, *i.e.* clouds consisting exclusively of ice crystals, are very frequent in the tropopause region. Since *in situ* formation of ice crystals takes place far away from thermodynamic equilibrium, large regions of the upper troposphere are in a state of super-saturation with respect to ice. Over the last twenty years, cirrus clouds and their potential formation regions (so-called ice-super-saturated regions) have been investigated using measurements (*e.g.* MOZAIC data), model simulations, and theoretical approaches. However, there is still lack of understanding of key processes related to the formation and evolution of cirrus clouds and ice-super-saturated regions. In support of this research, **Herman Smit** presented a reanalysis of upper tropospheric humidity data from MOZAIC for the period 1994-2009, data which are now available to the research community as part of the IAGOS database.

Closing remarks

The six symposium sessions highlighted new results based on MOZAIC data and other complementary programmes, surface networks, and satellite observations. Several speakers emphasized the need for combining observations from different measurement sources and the wish for a complete data set of atmospheric compounds and properties that could be used to further investigate scientific questions related to air quality and climate change – in line with the overall objectives of IAGOS. Many of the contributions presented during the symposium will be published in the MOZAIC-IAGOS special issue of Tellus B.

Routine aircraft observations provide invaluable information about atmospheric composition, helping to improve our understanding of global and regional air quality as well as the potential impact of greenhouse gases on climate change. Important results using MOZAIC and CARIBIC observations of ozone, water vapour, NO_y, and CO, looking at their global distributions and trends, have been published. Several of these studies contributed to the recent Task Force HTAP (2010) and IPCC (2014) reports.

Continued IAGOS operation has been assured through sustainable funding in the framework of international observing strategies such as GEOSS (Global Earth Observation System of Systems) and its European component Copernicus, as well as from national funding institutions. IAGOS builds on previous European initiatives using novel technological developments and there is a strong emphasis on expanding the network to cover the Pacific, North America, and further into the Southern Hemisphere. Its success relies heavily on the willingness of airlines to support operations. Finally, a sustainable governance structure, IAGOS-AISBL (Association Internationale Sans But Lucratif (Non-profit organization)), was implemented at the beginning of 2014 to ensure long-term operation and continuous data provision from IAGOS.

Acknowledgements

IAGOS gratefully acknowledges financial support during its preparation, implementation, and operation phase from the European Commission in FP6 and FP7 programmes, national research programmes in Germany (BMBF), France (INSU-CNRS, MESR, CNES), and the UK (NERC), in addition to institutional resources in Germany (Helmholtz Association, Max-Planck-Society, Leibniz Association), France (Université de Toulouse, Météo-France), and the UK (University of Manchester, University of Cambridge), and the continuing support of participating airlines (Lufthansa, Air-France, Iberia, Cathay Pacific, and China airlines).

References

Brenninkmeijer, C.A.M., *et al.*, 2007: Civil Aircraft for the regular investigation of the atmosphere based on an instrumented container: The new CARIBIC system. *Atmos. Chem. Phys.*, **7**, 4953-4976.

Baker A.K. *et al.*, 2011: Characterization of non-methane hydrocarbons in Asia summer monsoon outflow observed by CARIBIC aircraft. *Atmos. Chem. Phys.*, **11**, 503-518.

Clarke, A., and V. Kapustin, 2010: Hemispheric Aerosol Vertical Profiles: Anthropogenic Impacts on Optical Depth and Cloud Nuclei. *Science*, **329**, 1488-1492.

Cooper, O.R., *et al.*, 2014: Global distribution and trends of tropospheric ozone: An observation-based review. *Elem. Sci. Anth.*, **2**, 000029, doi: 10.12952/journal.elementa.000029.

Friedlingstein, P., *et al.*, 2006: Climate-carbon cycle feedback analysis: Results from the (CMIP)- M-4 model intercomparison. *J. Climate*, **19**, 3337-3353.

Gressent, A., *et al.*, 2014: Lightning NO_x influence on large-scale NO_y and O_3 plumes observed over the northern mid-latitudes, *Tellus-B*, **66**, 25544.

Lacis, A.A., *et al.*, 2010: Atmospheric CO_2: Principal Control Knob Governing Earth's Temperature. *Science*, **330**, 356-359.

Lenton, T., 2011: 2 degrees C or not 2 degrees C? That is the climate question. *Nature*, **473**, 7-7.

Mahowald, N., 2011: Aerosol Indirect Effect on Biogeochemical Cycles and Climate. *Science*, **334**, 794-796.

Min, S.K., *et al.*, 2011: Human contribution to more-intense precipitation extremes. *Nature*, **470**, 378-381.

Monks, P.S., *et al.*, 2009: Atmospheric composition change - global and regional air quality. *Atmos. Environ.*, **43**, 5268-5350.

Randel, W.J., *et al.*, 2010: Asian Monsoon Transport of Pollution to the Stratosphere. *Science*, **328**, 611-613.

Riese, M., *et al.*, 2012: Impact of uncertainties in atmospheric mixing on simulated UTLS composition and related radiative effects. *J. Geophys. Res.*, **117**, D16305, doi: 10.1029/2012jd017751.

Schuck, T.J., *et al.*, 2010: Greenhouse gas relationships in the Indian summer monsoon plume measured by the CARIBIC passenger aircraft. *Atmos. Chem. Phys.*, **10**, 3965-3984.

Schwartz, S. E., *et al.*, 2010: Why Hasn't Earth Warmed as Much as Expected? *J. Climate*, **23**, 2453-2464.

Solomon, S., *et al.* 2010: Contributions of Stratospheric Water Vapor to Decadal Changes in the Rate of Global Warming, *Science*, **327**, 1219-1223, doi: 10.1126/science.1182488.

Thouret V., *et al.*, 2000: General characteristics of tropospheric trace constituent layers observed in the MOZAIC program. *J. Geophys. Res.*, **105**, D13, doi: 10.1029/2000jd900238.

Thouret V., *et al.*, 2006: Tropopause referenced ozone climatology and inter-annual variability (1994-2003) from the MOZAIC programme. *Atmos. Chem. Phys.*, **6**, 1033-1051.

Report on the Latsis Symposium 'Atmosphere and Climate Dynamics' 18-21 June 2014, Zurich, Switzerland

Tapio Schneider[1]

[1]ETH Zurich, Switzerland, **tapio@ethz.ch**

Fundamental advances in climate modelling need to come from an improved understanding of the dynamical processes shaping climate, and their interactions across an enormous range of scales: from the micrometre scales of cloud droplet formation to the global scales of atmospheric circulations. Neither can be completely understood in isolation from the other, yet they are traditionally addressed in separate sub-communities that rarely interact with each other. The Latsis Symposium 2014, 'Atmosphere and Climate Dynamics: From Clouds to Global Circulations', was envisioned as a conference to bring together leading researchers from these diverse sub-communities in the climate sciences, in order to map out promising new avenues for research to answer the most pressing questions in climate dynamics. The meeting was primarily supported by the Geneva-based Latsis Foundation, which sponsors two annual conferences on topics from across the sciences. SPARC and other WCRP projects provided support for early-career scientists to attend the meeting.

About 200 scientists from 6 continents gathered in June for the four-day Latsis Symposium in Zurich, Switzerland. Each day consisted of one-hour invited overview lectures interspersed with shorter contributed talks and poster sessions. The topics of the overview lectures ranged from 'The Global Warming Hiatus in the Context of the Past Millennium' (**Mark Cane**), to 'Climate Change Uncertainty: The Role of Internal Atmospheric Variability' (**Clara Deser**) and 'Aerosol Forcing - Last Century's Problem' (**Bjorn Stevens**). The overview lectures formed the backbone of the symposium and structured the themes of the contributed talks in between.

One afternoon was devoted to interactive breakout sessions, which were anchored by invited talks in Pecha Kucha format: 5-minute talks consisting of 15 slides that each advanced automatically after 20 seconds (the format is used successfully, for example, at the World Economic Forum). In these very dynamic and engaging presentations, the speakers each introduced an important open question in climate dynamics and sketched ways of resolving it. The questions were then discussed in breakout groups, followed by a summary plenary. The Pecha Kucha talks and breakout groups addressed 'Transient Monsoon Dynamics: Understanding Synoptic and Subseasonal Variations'

(**William Boos**), ‘Polar Climate Dynamics: What Drives Arctic Amplification?’ (**Rodrigo Caballero**), ‘Tropical Precipitation Extremes: Can we Predict Their Response to Warming?’ (**Caroline Muller**), ‘Why Do GCMs Have Trouble With the MJO?’ (**David Randall**), and ‘General Circulation Dynamics: What Determines the Regional Response to Global Warming?’ (**Tiffany Shaw**).

Recurring Themes

A few recurring themes emerged from the broad range of talks and poster presentations: (1) There is a resurgence of interest in the dynamics of extra-tropical storm tracks. For example, presentations addressed how storm tracks equilibrate and vary on sub-seasonal timescales (**Maarten Ambaum**), and the great variety of processes that can influence their position: from orography (**Rachel White**), stratospheric processes (**Ted Shepherd, Gang Chen, David Ferreira**), baroclinic mechanisms (**Orli Lachmy, Cheikh Mbengue, Yu Nie, Yang Zhang)**, to cloud-radiative processes (**Dennis Hartmann**). Detailed dynamical descriptions of how extra-tropical storms lead to extreme events are emerging (**Brian Hoskins, Nili Harnik, Heini Wernli, Volkmar Wirth**). What is missing is a closed theory that relates the position and energy of extra-tropical storm tracks to mean climate variables such as the thermal structure of the atmosphere. (2) Atmosphere-ocean interactions are important contributors to decadal climate variations and modulators of long-term climate changes, but they remain insufficiently understood. For example, El Niño and the Southern Oscillation (ENSO) appear to be linked to climate variations in higher latitudes, with implications for the recent global warming hiatus (**Mark Cane**). Yet the nature of such links, and their implications for climate changes on geological time scales, remain to be clarified (**Riccardo Farneti, Alexey Fedorov, Malte Stuecker, Jin-Yi Yu**). Similarly, spatially varying ocean uptake of energy and carbon strongly and non-linearly modulates the long-term response to climate change; however, the dynamics controlling the spatial pattern of that uptake are not fully understood, leading to uncertainties in climate projections (**Kyle Armour, David Brayshaw, Nicole Feldl, Thomas Frölicher, Brian Rose**). Clearly, we need an improved understanding of how processes in the upper ocean couple both to the atmosphere above and to the deep ocean below. (3) The hydrologic cycle and how it responds to climate changes remain areas of intense research. Recent work addresses how stationary circulations, both thermally and orographically driven, shape patterns of net precipitation (precipitation minus evaporation) and their changes with climate (**Xavier Levine, Isla Simpson, Robert Wills**). Observations and theories of how precipitation and net precipitation more broadly have changed over the past decade and are expected to change in the future are being refined (**Michael Byrne, Peter Greve, Angeline Pendergrass**), as is our understanding of what controls atmospheric humidity and its variability (**William Collins**). (4) Substantial progress is being made in observing, modelling, and understanding the processes controlling clouds and convection, but these processes remain at the heart of our uncertainties about how the climate system responds to perturbations. The multitude of processes that influence clouds and convection - from large-scale overturning circulations to the microphysics of droplet formation - continue to make it challenging to arrive at a comprehensive theory or at least a clear understanding of the relative importance of the various processes. Yet progress is being made in designing frameworks for simulating these processes (**Adam Sobel, Isaac Held**) and in using observations and high-resolution simulations to elucidate, for example, how important different processes are for convective self-aggregation (**Allison Wing, Adrian Tompkins**) and how complex the representation of clouds and convection in climate models needs to be (**David Randall**). The Madden-Julian Oscillation is a good test bed of our understanding of how convection, surface exchange processes, and tropical waves interact, and it came up in several presentations (**Larissa Back, Henrik Carlson, Penelope Maher, Brian Mapes**). There continues to be debate about the importance of changes in aerosol loading on clouds (**Bjorn Stevens, Ulrike Lohmann**); however, progress is being made observing aerosol effects and modelling them through high-resolution simulations (**Chris Bretherton, Doris Folini, Franziska Glassmeier**). Conversely, the radiative effects of clouds on large-scale circulation features such as the ITCZ (**Romain Roehrig, Aiko Voigt**), ENSO (**Gaby Raedel**), and storm tracks (**Dennis Hartmann**) are increasingly studied and evidently play a role in modulating the circulation response to global warming. (5) It made for a particularly stimulating, albeit intense, meeting that this breadth of themes was presented in close succession in just four days, in one auditorium where all attendees remained together. The meeting made it clear that the observational data and computational tools we now have at our disposal present rich new opportunities for studying and resolving questions in atmosphere and climate dynamics that are at the centre of how the climate system responds to perturbations on timescales from years to geological epochs.

Early-Career Scientists

WCRP, through its core projects SPARC, GEWEX, and CLIVAR, provided travel support for early-career scientists. With additional support by the ETH Centre for Climate Systems Modelling, in total 33 early-career scientists received travel support to attend the meeting, which was crucial in ensuring that a large number of younger scientists could participate and carry lessons learned from it to the future (about half of the participants were early-career scientists).

The overall impression that the meeting left is that the field of atmosphere and climate dynamics is successfully completing a generational transition. New approaches are being developed to address questions that sometimes go back decades (*e.g.*, about extra-tropical storm tracks and atmosphere-ocean interactions). Their resolution now seems within reach.

Report on the SPARC Workshop on Polar Stratospheric Clouds 27-29 August 2014, Zurich, Switzerland

Ines Tritscher[1], Michael C. Pitts[2], Lamont R. Poole[3], and Thomas Peter[4].

[1]Forschungszentrum Jülich, Germany, **i.tritscher@fz-juelich.de**, [2]NASA Langley Research Center, USA, [3]Science Systems and Applications, Incorporated, USA, [4]ETH Zürich, Switzerland

A workshop on Polar Stratospheric Clouds (PSCs) was held at ETH Zurich in Switzerland from 27-29 August 2014 and was attended by 44 scientists from 10 different countries. The workshop provided a platform to link the various individual activities underway and to assess key science developments related to PSCs. The organizers sought to encourage discussion of new observations and modelling results, identify outstanding science questions, and relate recent results to long-standing conundrums. The workshop was organized into five sessions: 'Satellite and Ground-based Lidar Observations'; 'Aircraft and Balloon-borne Observations'; 'Processes: Nucleation, Denitrification, Dynamical Forcing'; 'Chemistry and Chemistry Transport Models (CTMs)'; and 'PSC Parameterization in Chemistry Climate Models (CCMs) and Empirical Studies'. To facilitate dialogue amongst participants, dedicated discussion periods were set aside at the end of each session. A workshop steering group meeting was held on the Friday afternoon to summarize the outcomes of the workshop and discuss the content of a potential new and comprehensive paper on PSCs.

The workshop was kicked off by **Thomas Peter** who presented a historical perspective of the evolution of our understanding of PSCs. Almost three decades after the discovery of the ozone hole, he concluded that our understanding of PSC-catalysed heterogeneous chemistry is probably sufficient, whereas our knowledge about nitric acid hydrate PSC nucleation and denitrification is still incomplete. Gaps and uncertainties in our understanding make it difficult to fully parameterize PSC-related processes in global models. With Thomas' presentation, the stage was set for individual contributions from various research fields.

Satellite and Ground-based Lidar Observations

Observations from the CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarisation), MIPAS (Michelson Interferometer for Passive Atmospheric Sounding), and Aura MLS (Microwave Limb Sounder) satellite instruments were presented by **Michael Pitts**, **Michael Höpfner**, and **Alyn Lambert**, respectively. CALIOP, on-board the CALIPSO satellite, has been providing a detailed picture of PSC morphology and composition on vortex-wide scales since 2006. The CALIOP algorithm separates PSCs into different composition classes including super-cooled ternary solution (STS) droplets, mixtures of liquid droplets and nitric acid trihydrate (NAT) particles in varying number concentrations, as well as ice. Composition discrimination is possible based on the ensemble 532nm scattering ratio (the ratio of total-to-molecular backscatter) and the 532nm particulate depolarisation ratio (which is sensitive to the presence of non-spherical particles, *i.e.* NAT and ice particles). The coordinated, nearly coincident measurements from Aura MLS and CALIOP within the A-Train satellite constellation allow a detailed study of lidar PSC signatures simultaneously with measurements of gas-phase species such as water (H_2O) and nitric acid (HNO_3). HNO_3-uptake by liquid- and solid-phase PSCs and examples of the processes of denitrification, dehydration, and chlorine activation were shown. Complementary information about PSCs can be deduced from measurements in the mid-infrared from MIPAS on Envisat. The spectral information allows the discrimination of different forms of NAT (alpha-NAT and beta-NAT), but there has been no indication of the presence in the atmosphere of nitric acid dihydrate (NAD). **Peggy Achtert** concluded the oral presentations in this session with a synopsis of 18 years of PSC observations from the ground-based lidar at Esrange, Sweden. The location of Esrange in the lee of the Scandinavian mountains allows observation of a wide range of PSC growth conditions influenced by mountain-wave activity.

The pros and cons of PSC composition classification schemes were discussed after the presentations. There was agreement that classification schemes are needed to observe trends and compare observations with models. However, a clear description needs to be delivered together with the classification scheme to avoid discrepancies. A classification scheme should be based on physical, rather than purely empirical properties. To achieve this goal, it was suggested that parameters like temperature, HNO_3-, and H_2O- content could be systematically combined with the classification scheme. However, the question of classification should not be mixed with the interpretation of processes.

Six posters related to 'Satellite and Ground-based Lidar Observations' were also presented. **Michael Pitts** described a new approach for CALIOP PSC composition classification that discriminates NAT mixtures based on the instantaneous HNO_3 sedimentation flux of NAT particles instead of NAT number density. **Reinhold Spang** introduced an improved PSC classification scheme based on MIPAS multi-spectral measurements and showed first results from a new MIPAS PSC climatology. A poster by **Marion Maturilli** described the long-term PSC data record from the ground-based lidar at the Arctic Research Station AWIPEV in Ny-Ålesund, Svalbard. **Marcel Snels** analysed observations from the ground-based lidar at McMurdo Station, Antarctica, to evaluate the morphology of PSCs and investigate how processes acting at different spatial scales may affect PSC formation. **Lamont Poole** examined PSC observations by the SAGE-III satellite instrument over the Arctic, discussing similarities and differences in PSC composition from these data relative to that inferred from CALIOP Arctic observations. **Tobias Wegner** utilised CALIOP PSC optical depth data as input to a state of the art radiative transfer model to investigate the radiative impact of PSCs.

Aircraft and Balloon-borne Observations

Sergej Molleker opened the 'Aircraft and Balloon-borne Observations' session with a presentation of *in situ* measurements of PSC particle size distributions obtained from the Geophysica aircraft over the Arctic in January 2010 and December 2011. Measurements of exceptionally large HNO_3-containing particles with diameters of up to 35µm cannot be explained by spherical NAT particles whose particle-phase HNO_3 mixing ratios would exceed available stratospheric concentrations. Sergej hypothesized that either strongly aspherical particle shapes or a different chemical composition (*e.g.*, water-ice coated with NAT) could explain the observations. The hypothesis of aspherical NAT particles was also explored by **Wolfgang Woiwode**, who examined the vertical redistribution of HNO_3 by NAT particles using a combination of MIPAS-STR aircraft observations and CLaMS model simulations. The best agreement between model and observations was found with a NAT particle settling velocity reduced to 70% of that for spheres, leading to the speculation that the shape of large NAT particles may be compact platelets or needles. Recent *in situ* measurements of the non-volatility of sub-micron aerosol particles within the Arctic polar vortex were then presented by **Stephan Borrmann**. The COPAS (Condensation Particle Counter System) instrument on-board the Geophysica aircraft measured a general increase of sub-micron particle number densities with altitude inside the polar vortex, with non-volatile cores in 70% of the particles. Although debatable, the detected non-volatile cores are assumed to be predominantly of meteoric origin. In addition, Stephan presented preliminary results from nucleation experiments in the AIDA (Aerosol Interaction and Dynamics in the Atmosphere) chamber and pointed out the need for more laboratory experiments. **Christoph Kalicinsky** presented first results of HNO_3 retrievals within PSCs from the CRISTA-NF (Cryogenic Infrared Spectrometers and Telescopes for the Atmsophere) instrument on-board the Geophysica aircraft. Denitrified and renitrified layers seen by the CRISTA-NF were found to be consistent with SIOUX (StratospherIc Observation Unit for nitrogen oXides) NO_y observations and CLaMS simulations. **Terry Deshler** concluded the session with a presentation describing quasi-Lagrangian measurements of PSC particles and temperature from long-duration balloon flights in the late austral winter of 2010. The change in the number of NAT particles measured over time was used to infer an observationally-based NAT nucleation rate of approximately 2×10^{-4} $m^{-3}s^{-1}$.

The subsequent discussion session focused on the open question of what are the most likely nuclei for NAT particles and how can we unequivocally determine the composition and source of these nuclei? Impactor measurements during the RECONCILE aircraft campaign revealed metals, silicates, and lead as primary constituents of the non-volatile particles. Does this fit into our general picture? These RECONCILE results are controversial and hopefully will serve to motivate additional measurements.

Two posters related to 'Balloon-borne and Aircraft PSC Observations' were also presented. **Sabine Grießbach** used radiative transfer calculations including scattering to show that the spectra measured by the CRISTA-NF instrument on-board the Geophysica are consistent with the *in situ* measured size distribution of PSC particles. **Sergey Khaykin** presented high-resolution observations of water vapour and PSCs obtained from balloons and the Geophysica aircraft to document dehydration in the Arctic stratosphere.

Processes: Nucleation, Denitrification, Dynamical Forcing

'Processes: Nucleation, Denitrification, Dynamical Forcing' was the opening session on the second day of the workshop. With knowledge of the existence of non-volatile nuclei within the polar vortex, heterogeneous nucleation becomes a likely pathway for PSC formation. **Ines Tritscher** presented evidence for heterogeneous NAT and ice formation pathways based on observations, modelling studies, and laboratory experiments. **Beiping Luo** used similar

Figure 6: Participants of the SPARC PSC Workshop held in July 2014 in Zurich, Switzerland.

parameterizations for cirrus modelling studies and emphasized the quality of meteoritic dust particles as heterogeneous nuclei. **Alexander James** presented results from more detailed laboratory studies of the phase of nitric acid hydrate formed upon crystallization of nitric acid solution droplets using Raman and x-ray diffraction techniques. Alexander reported that NAT never forms in controlled laboratory experiments, with NAD forming instead. He speculated that the presence of sulfuric acid (H_2SO_4), as is the case in the real atmosphere, may be required to trigger NAT nucleation. **Daniel Murphy** then discussed the effects of small-scale dynamics on PSCs. He showed that the non-linear nature of ice nucleation produces fine-scale structures within a cloud. Studies with parcel and one-dimensional models showed that even when cooling rates are high, heterogeneous nucleation is not necessary to form a few large ice crystals. Other processes that can lead to large crystals include sedimentation from the bottom of a PSC, natural selection from unusual temperature histories, annealing of disordered ice, and entrainment.

During the follow-up discussion session, there was consensus that heterogeneous NAT and ice nucleation on non-ice nuclei is a viable pathway. Again, questions related to the source and composition of the nuclei were discussed, along with additional uncertainties such as number densities, nucleation quality and mechanisms, all of which are important for modelling studies. Open questions include: What level of detail is required to accurately simulate processes such as denitrification? And, are there differences between the Northern and Southern Hemispheres?

Four posters were also presented in this session. **Masashi Kohma** examined the simultaneous occurrence of PSCs and upper tropospheric clouds caused by blocking anticyclones. **Andreas Dörnbrack** presented measurements from the GW-LCYCLE field campaign showing deeply propagating gravity waves from the surface to the mesosphere. **Nadège Montoux** presented results from a case study connecting Antarctic ground-based and space-borne lidar measurements by a Lagrangian MATCH approach, together with microphysical modelling. **Ines Tritscher** showed that a heterogeneous nucleation mechanism for synoptic-scale ice PSCs is required to explain and reproduce the CALIPSO PSC observations from the 2009-2010 Arctic winter.

Chemistry and CTMs

An ongoing, intensively discussed topic is the role of PSCs for chlorine activation. **Rolf Müller** opened the 'Chemistry and CTMs' session with a presentation about the relative roles of heterogeneous and gas-phase processes for polar chlorine activation and ozone loss. He concluded that the chemistry of polar chlorine activation and ozone loss is largely controlled by the speed of gas-phase reactions. Most important for polar ozone loss is the length of the period below a certain temperature threshold, which he termed the 'PSC-vegetation period'. **Jens-Uwe Grooß** addressed the question 'Does complete ozone depletion require certain temperatures and/or PSC types?' He concluded that the main difference between the Arctic and the Antarctic stratosphere with respect to complete ozone depletion is (1) the time below a certain temperature threshold of about 195K, which agrees with the conclusion of Rolf, and (2) the initial ozone mixing ratio in early winter which is higher in the Arctic. **Hideaki Nakajima** presented observational evidence from CALIOP and MLS of vortex-wide chlorine activation by a mesoscale PSC event during the 2009-2010 Arctic winter. His results indicated that the chlorine activation itself was insensitive to PSC type. **Ross Salawitch** concluded the session with an overview of chlorine monoxide (ClO) and bromine monoxide (BrO) gas-phase chemistry in the polar stratosphere. He indicated that large uncertainties exist, namely in the kinetics of BrO + ClO and in the supply of bromine to the stratosphere by very short-lived bromocarbons.

Seven posters were presented related to this session. **Francesco Cairo** showed results from a case study investigating the role of solid and liquid PSC particles in heterogeneous chemistry and denitrification in the late winter in the Antarctic lower stratosphere. **Martyn Chipperfield** used simulations from the TOMCAT/SLIMCAT CTM to examine to what extent chlorine activation on NAT particles is important. **Wuhu Feng** also utilised TOMCAT/SLIMCAT simulations to quantify the effect of denitrification on ozone loss for several Arctic winters. **Ingo Wohltmann** used the ATLAS model to examine the role of PSC particle composition in chlorine activation during the 2009-2010 Arctic winter and concluded that NAT clouds played a relatively small role compared to liquid clouds in this winter. **Jens-Uwe Grooß** showed that a new saturation-dependent parameterization of heterogeneous NAT nucleation rates in the CLaMS model generally reproduced PSC optical properties observed by CALIOP better than those simulated with a constant rate model. Both **Tobias Wegner** and **Martyn Chipperfield** presented posters discussing the observed depletion of hydrogen chloride in the Antarctic polar vortex and the ability of CCMs to reproduce this feature.

PSC Parameterizations in CCMs and Empirical Studies

The 'PSC Parameterizations in CCMs and Empirical Studies' session started with a presentation by **Douglas Kinnison** on PSC representation in the WACCM model. He showed that WACCM's non-equilibrium approach agrees well with observations. Although the specific PSC approach used in WACCM to obtain realistic gas-phase HNO_3 values at the end of the winter is important, the details of the PSC evolution and composition are secondary. **Susan Solomon** followed up on the discussion from the 'Chemistry and CTMs' session with a presentation on important constraints on the role of PSCs in ozone depletion. In contrast to previous presentations, she emphasized that temperatures below 192K are required to match observed ozone losses. She stressed the importance of individual processes, which, once summed together, matter. The balance between activation and deactivation varies with space, time, temperature, solar illumination, surface area, reactivity, denitrification, Cl_y concentrations, and other factors. It is not purely a local process. Transport may connect air with faster photolytic processes to air deeper within the vortex and edge regions can reach well into the vortex too. **Federico Fierli** examined the parameterization of PSCs in CCMs by comparing Antarctic PSC climatologies with CCM simulations. He identified a large spread between the different CCMVal (SPARC Chemistry Climate Model Validation) models looking at maximum surface area densities and spatial distribution of PSCs. However, the agreement between space- and ground-based lidars is at least partly satisfactory. The last presentation of the workshop was given by **Markus Rex**, who talked about the long-term evolution of PSC volumes above the Arctic in cold winters based on a variety of meteorological reanalysis data sets. The potential PSC volume correlates well with ozone loss. However, a trend towards increasing PSC volumes indicating that the coldest Arctic winters have become colder was recently called into question. Markus showed that the definition of statistical significance as well as the specific statistical approach used may lead to conflicting results and influence the conclusions.

The discussion afterwards focused on model development. There is a general need for simplification to translate our knowledge of PSC processes into global models. However, this task requires a detailed knowledge to judge the importance of different processes. Climate change may also challenge our understanding of PSCs and ozone loss.

Two posters were presented related to this session. **Farahnaz Khosrawi** examined the sensitivity of PSC formation and existence to changes in water vapour and concluded that a potential increase in stratospheric water vapour of 1ppmv and a cooling of 1K will clearly prolong the time period during which PSCs can form and exist. **Andrew Orr** demonstrated the importance of including a mountain-wave induced cooling parameterization in CCMs to accurately simulate PSC formation.

Steering Group Meeting

A steering group meeting was held on the Friday afternoon after the workshop to discuss the value of putting together a comprehensive PSC overview paper. The steering group decided to support the idea of a common publication and collected ideas about content and target audience. With the focus of recent measurements and findings, observations should be summarized and harmonized in this paper in a way useful to the global modelling community. PSC properties such as surface area density, which could be used as model input, and climatologies of various gas-phase species as reference for model evaluation should be considered for inclusion. Hemispheric differences should also be emphasized.

In summary, the SPARC umbrella attracted many scientists with a broad expertise in PSC science. We are looking forward to future activities and publications emerging from the workshop in Zurich.

Report from the 10th SPARC data assimilation workshop and the 2014 SPARC Reanalysis Intercomparison Project (S-RIP) workshop in Washington DC, USA

Quentin Errera[1], Masatomo Fujiwara[2], Craig Long[3], and David Jackson[4].

[1]Belgian Institute for Space Aeronomy, Belgium, **quentin@oma.be**, [2]Hokkaido University, Japan, [3]NOAA Center for Weather and Climate Prediction (NCWCP), Maryland, USA, [4]UK Meteorological Office, UK

The 10th SPARC Data Assimilation (SPARC DA) workshop and the 2014 SPARC Reanalysis Intercomparison Project (S-RIP) workshop were held together at the National Oceanographic and Atmospheric Administration (NOAA) Center for Weather and Climate Prediction (NCWCP) in College Park (Maryland, USA), close to Washington DC, from 8-12 September 2014. Days one and two were dedicated to scientific presentations and discussion related to SPARC DA activities, days four and five were dedicated to discussion on the progress of S-RIP and on day three a joint session between both activities was held. The 10th SPARC-DA workshop was one of a regular series (see **http://www.sparc-climate.org/activities/data-assimilation/**) that started in 2002 and had around 25 participants, while the 2014 S-RIP workshop was the first ever after a 2013 planning meeting (Fujiwara and Jackson, 2013) and also had around 30 participants. About 45 participants attended the joint workshop on day three.

The S-RIP activity emerged after discussions held at the 8th and 9th SPARC DA workshops and therefore it is only natural to have a shared location and week with workshops for both activities. Moreover, many people involved in one of the two activities were happy to participate in a one-day joint meeting with scientific talks about using and creating reanalysis data products.

Observation requirements and exploitation of new observations for stratosphere-troposphere data assimilation

Pawan Bhartia (invited) presented the capabilities and potential applications of the Ozone Mapping and Profiler Suite (OMPS) Limb Profiler (LP) launched in October 2011 for the study of atmospheric chemistry and dynamics. The OMPS LP measures limb scattered radiances and solar irradiances from 275-1050nm. The sensor employs three horizontally separated vertical slits to provide wider cross-track coverage. Ozone profiles are retrieved from cloud top altitude to 60km from 84°N-84°S during daylight hours with a vertical resolution of around 2km. The instrument also provides profiles of aerosols extinction at five wavelengths from cloud top altitude to 35km. OMPS LP version 2 Ozone data agree well with observations from Atmospheric Chemistry Experiment Fourier Transform Spectrometer (ACE-FTS), Microwave Limb Sounder (MLS), and ozonesondes. The version 2.5 data, to be released in 2015, are supposed to show even better agreement. The end of the presentation highlighted the potential use of data assimilation of LP data along with total ozone provided by the Nadir Mapper (NM) and Cross-track Infrared Sounder (CrIS), also onboard OMPS. This would allow getting a good ozone analysis thanks to the good vertical resolution of LP in the stratosphere, the sensitivity of NM in the troposphere and the sensitivity of CrIS in the Upper Troposphere and Lower Stratosphere (UTLS).

Lawrence Coy discussed several improvements realized in the second release (planned for early 2015) of the Modern Era Retrospective analysis for Research and Applications (MERRA-2), a reanalysis covering the period 1979-2015. The tuning of the gravity wave parameterization has been improved and allows a much better model representation of the Quasi Biennial Oscillation (QBO) than in the model used in the first MERRA release. MERRA-2 also benefits from an upgrade of the orographic gravity wave scheme to better represent gravity waves over Southern Hemisphere islands. Other improvements come from new assimilated observations. Temperature profiles measured by MLS are now assimilated from 2004 onwards, reducing the high temperature bias in the mesosphere seen in MERRA. For example, during the period of the

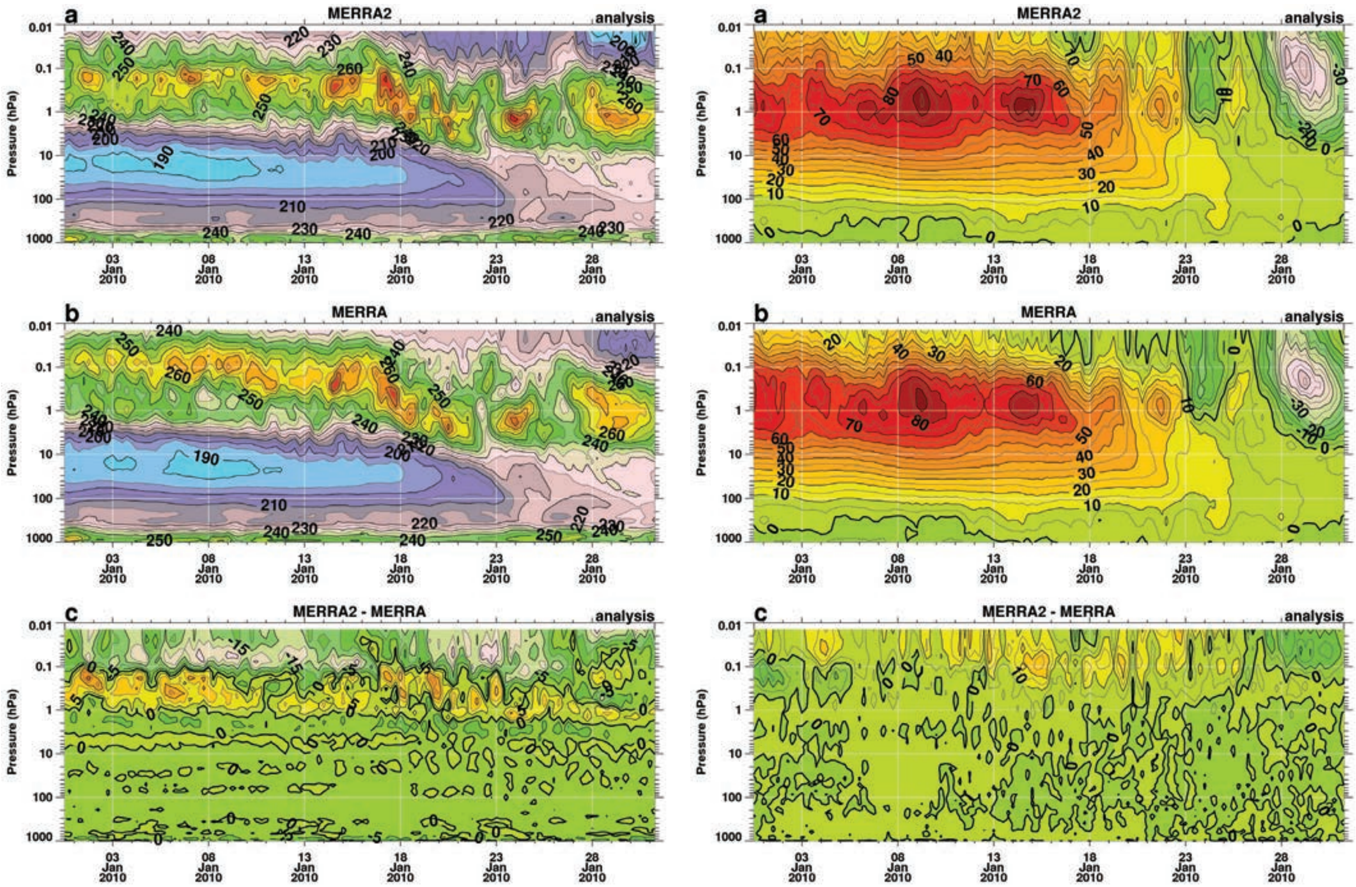


Figure 7: Time series of temperature averaged from 60°N-90°N (left) and zonal wind at 60°N (right) from MERRA-2 (top), MERRA-1 (middle), and their differences (bottom), for January 2010 when a stratospheric sudden warming occurred. (Provided by Lawrence Coy).

Stratospheric Sudden Warming in 2010 (see **Figure 7**), MERRA-2 shows a lower stratopause and cooler mesosphere than MERRA. Interestingly though, mesospheric zonal wind is stronger in MERRA-2 than in MERRA.

Troposphere/stratosphere/ mesosphere interactions: Stratosphere & Troposphere

Andrea Lang (invited) presented an overview and the current status of the SPARC Stratosphere Network for the Assessment of Predictability (SNAP) activity (Charlton-Perez and Jackson, 2012). The goal of SNAP is to understand the role of the stratosphere in numerical weather predictions. Several case studies have been defined and are being analysed with the different Numerical Weather Prediction (NWP) systems participating in SNAP. She showed results of predictability for the northern hemisphere sudden stratospheric warming (SSW) in early 2013. All the models failed to predict the warming 15 days in advance, and had a huge spread of zonal wind predictions at 10hPa and 60°N (60m.s^{-1} after 15 days). However, all models can essentially simulate the SSW if initialized 10 days in advance. By focusing on the 'best' and 'worst' ensemble members, she showed that all models struggle to simulate the amplification of wave-2 structure in the stratosphere, while amplification of wave-2 in the troposphere as well as amplification of wave-1 in both regions was relatively well resolved by the models.

Gloria Manney studied the effect of SSWs on the composition of the UTLS using meteorological analyses and satellite data. Six SSWs have occurred in the past decade and it was shown that during SSW years disturbances of the polar vortex lead to very early chlorine activation and substantial ozone loss in December and January. These disturbances were accompanied by changes in the patterns of upper tropospheric jets and the increased occurrence of multiple tropopauses. **Jean de Grandpré** evaluated the ozone predictability of the operational Environment Canada Chemical Data Assimilation (EC-CDA) system. Several numerical experiments were conducted using different ozone datasets, namely, data from MLS, Global Ozone Monitoring Experiment-2 (GOME 2) and Solar Backscatter Ultraviolet Radiometer (SBUV) instruments.

The experiments were evaluated in terms of their skill in forecasting ozone anomaly correlations. When coupling between the modelled ozone and radiation is considered, the system showed better stratospheric temperature forecasts when assimilating MLS ozone data. When assimilating GOME-2 instead of MLS, the gain in predictability is half a day after ten days of prediction. In the case of assimilating SBUV observations instead of GOME-2, the loss in predictability is greater than one day. Finally, removing the a priori ozone profile from the SBUV retrieval using averaging kernels did not significantly improve the forecast skill.

Using the coupled whole-atmosphere/ionosphere model of NOAA's Integrated Dynamics in Earth's Atmosphere (IDEA), **Houjun Wang** made the first 'weather forecast' (with this kind of model) of the January 2009 SSW. He used data assimilation up to 80km (the model upper boundary is at around 600km), with incremental analysis update, and no digital filtering to ensure accurate representation of tides. IDEA successfully predicts both the time and amplitude of peak warming in the polar cap region, with the 10-day forecast being superior to the standard NOAA NWP model (GFS). The observed impact of this SSW on the ionosphere includes enhanced (reduced) vertical drift velocity from the product of the electric and magnetic fields around 08-10Z (10-14Z), and IDEA seems to represent this well. The drift velocity changes and associated changes in ionospheric total electron content are related to changes in lower thermospheric tides. The forecast of the semi-diurnal, westward-propagating zonal wave number 2 (SW2) tide in zonal wind also shows an increase in amplitude and a phase shift to earlier hours in the equatorial dynamo region during and after the peak warming, before recovering to prior values about 15 days later. The SW2 amplitude and phase changes were shown to likely be due to changes in stratospheric circulation and associated stratospheric ozone changes.

Richard Ménard presented results from a study group looking at the added value of upper-tropospheric and stratospheric chemical data assimilation. While chemical data assimilation systems are more and more mature and despite the high number of observations available in these regions, few applications of these analyses have been found. This group, supported by the International Space Science Institute (ISSI) in Bern, Switzerland, is based on assimilators and potential users. Potential products are a reanalysis of methane and CFCs to make a linearized chemical scheme to be used in climate models (see also the summary of Quentin Errera's talk below).

Troposphere/stratosphere/mesosphere interactions: Upper Atmosphere

John McCormack (invited) discussed the recent progress of the Naval Research Laboratory (NRL) NWP systems at high altitude. He showed that assimilation of radiances from SSMIS (Special Sensor Microwave Imager/Sounder) was able to constrain mesospheric temperature nearly as well as profile assimilation of MLS and SABER (Sounding of the Atmosphere using Broadband Emission Radiometry). John also showed how a new linearized water vapour photochemical scheme significantly improved the water vapour analysis in the stratosphere and mesosphere, reducing model temperature biases through a better representation of infrared radiation and enabling assimilation of additional radiance observations from IASI (Infrared Atmospheric Sounding Interferometer). Last but not least, he noted that many scientists are concerned by the lack of plans for new limb sounders, but also mentioned the lack of plans for future upper atmospheric radiance sounders like SSMIS.

David Jackson presented an extension of the UK Met Office Unified Model (UM) to the thermosphere, which is aimed at improving space weather forecasts in the long term. Development of the UM is focused on two areas. One concerns lifting the model lid up to 120-140km to allow better coupling between the lower and upper atmosphere and to enable assessment of the UM tidal climatology against meteor radar and other observations. Initial UM simulations with UM lids at 100km and 120km are promising, but there are issues regarding tuning of the model non-orographic gravity waves scheme and with model stability. The second area focuses on improvement of the dynamical core of UM above 120km. Idealized tests show that the representation of acoustic waves are challenging in this region.

Valery Yudin discussed data analysis and whole atmosphere predictions calculated with the chemistry-climate model WACCM. He highlighted the need for profile assimilation to reproduce vertical structures of observed ozone laminas and severe ozone losses as, for example, during the 2011 Arctic winter. Valery also presented results from a new version of WACCM with the lid extended from 140km to 500km. Using observations from the TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics) and GPS (Global Positioning System) TEC (Total Electron Content), he evaluated WACCM simulations where the dynamics was specified by meteorological analysis in the lower atmosphere. This simulation was able to reproduce several observed features like tidal variability in the ionosphere-thermosphere during various SSW events between 2006 and 2013.

DA Methods

Karl Hoppel explored the background forecast error covariances of the middle atmosphere as simulated by the NRL NWP system. Forecast error covariances were estimated using two methods: (1) forecast field differences at 24 and 48 hours and (2) a random observation denial method. A rapid increase in error variance in the mesosphere was observed, along with unexpectedly large horizontal correlation patterns. The breakdown of geostrophic correlation at small scales (<1000km) was also observed in the mesosphere. By performing a spectral decomposition of analysis errors, the predictability limit as a function of resolution was inferred (**Figure 8**). The skill-resolution was found to decrease with increasing altitude, reaching values of around six degrees (wavenumber 30) in the upper mesosphere for temperature, and similar values for vorticity and divergence.

Data assimilation products in support of SPARC activities

Michaela Hegglin (invited) discussed the value of data assimilation products for the IGAC/SPARC Chemistry Climate Model Initiative (CCMI). Two examples using the Canadian Middle Atmosphere Model (CMAM) nudged to ERA-Interim reanalysis were discussed. The first presented a study of stratospheric ozone between 1960 and 2010 (Shepherd *et al.*, 2014). Thanks to model simulations using evolving and fixed amounts of ozone depleting substances, several remaining questions about observed ozone trends could be answered and the onset of ozone recovery identified. In the second example (Hegglin *et al.*, 2014), a CMAM simulation was used as a transfer function between different satellite water vapour datasets in order to remove biases between instruments and to create a long-term (mid-1980 to 2010) water vapour record for the stratosphere. A negative trend is found in lower/mid-stratospheric water vapour, implying that the positive trend observed in balloon observations over Boulder (USA) is not globally representative. In the upper stratosphere, the water vapour trend is positive. The difference in sign between the trend in the lower and upper stratosphere was attributed to changes in the Brewer Dobson circulation (BDC). Together, these two examples highlighted not only the high quality of the ERA-Interim reanalysis, but also revealed an inhomogeneity where GPS Radio Occultation observations started to be fed into the assimilation system.

Simon Chabrillat presented the Near Real Time (NRT) ozone analyses delivered by the European

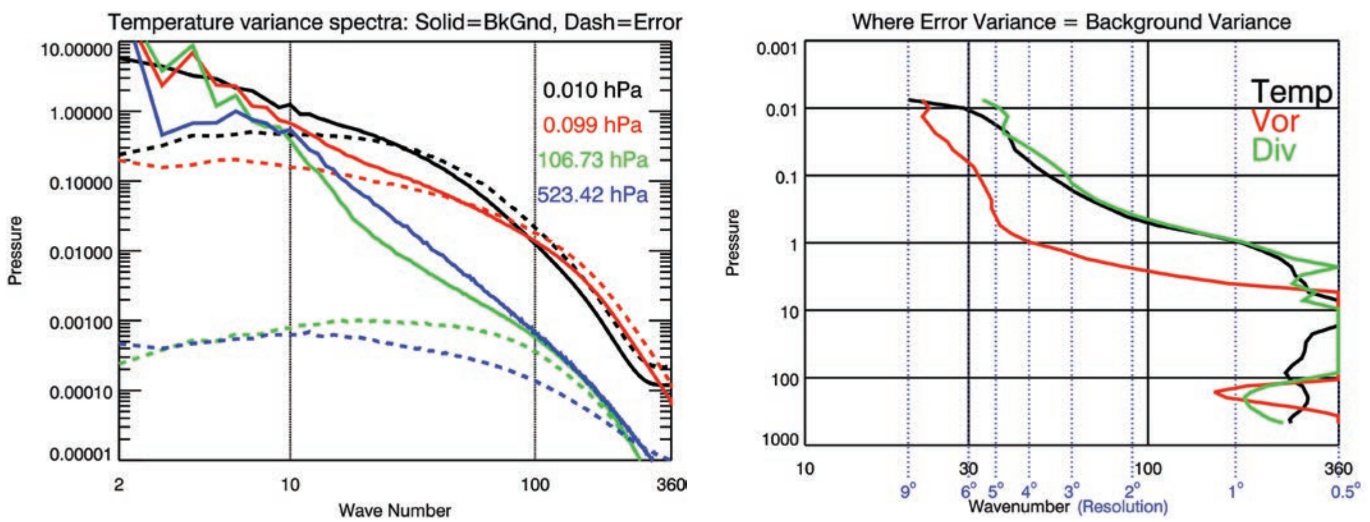


Figure 8: (left) Average power spectra for temperature forecast (solid line) and temperature analysis error (dashed lines) for several pressure levels. (right) Limit of predictability, defined as the wavenumber where the error variance exceeds the forecast variance. Analysis errors for temperature (black), vorticity (red), and divergence (green) were estimated as the difference between two December 2011 analyses produced from a random-observation denial experiment. (Provided by Karl Hoppel).

project MACC (Monitoring Atmospheric Composition and Climate). Due to NRT constraints, the system assimilates the NRT MLS ozone observations delivered three hours after measuring time and not the scientific MLS ozone data delivered around four days later. Due to the differences between these MLS datasets, the latter providing a better product, ozone fields from MACC are found to be of lower quality than those expected if the system could afford a four day delay (Lefever *et al.*, 2014).

Kris Wargan investigated the occurrence of Tropopause Inversion Layer (TIL) in the Goddard Earth Observing System version 5 (GEOS-5). Past studies have shown that the TIL is well represented in models but is erased in meteorological analysis by coarse assimilated data. GEOS-5 and more recent NWP systems exhibit the TIL correctly and numerical experiments performed with GEOS-5 demonstrate that the TIL is indeed erased if low spectral resolution data, such as from the Advanced Microwave Sounding Unit A (AMSU-A), are assimilated exclusively. It was shown that the use of hyperspectral radiance data and conventional observations in GEOS-5 is critical for reproducing the feature. In fact, full data assimilation with GEOS-5 leads to a TIL that is sharper (and closer to radiosonde observations) than the model-only simulation.

Using different NWP reanalyses, **Jianjun Xu** compared stratospheric temperature trends for the 1979-2005 period from radiosondes, satellite microwave radiances, and model simulations of the Coupled Model Intercomparison Project (CMIP) phase 3 and 5. He also compared the spread of trends based on the variability in the different datasets. His analysis revealed that reanalyses overestimate tropospheric warming and underestimate stratospheric cooling compared to that observed by radiosondes. Variability between the different reanalyses is also much higher than that present in the different radiosonde datasets.

Another trend evaluation using different reanalyses was done by **Toshiki Iwasaki**, who compared the evolution of the polar cold air mass (PCAM) in the troposphere. PCAM is defined as the quantity of air with a potential temperature below 280K and is a good indicator of the life cycle of polar cold air, from generation to disappearance. In the northern hemisphere winter, all reanalyses show a negative PCAM trend, on average decreasing by 5% over the past 50 years. This quantity seems to be sensitive to climate change. In the southern hemisphere winter, the PCAM trend is less consistent between different reanalyses, probably because of sparse surface and radiosonde data available for the assimilation procedure.

Craig Long presented preliminary test results from assimilation of Stratospheric Sounding Unit (SSU) and AMSU radiances into the National Center for Environmental Prediction (NCEP) Global Forecast System (GFS). The tests were being conducted to address issues in the Climate Forecast System Reanalysis (CFSR) during the transition from the SSU to the AMSU radiances in October 1998. Issues with the CFSR associated with radiance assimilation in the stratosphere included: breaking up the reanalysis into six streams, bias correction of SSU Channel 3, and not assimilating AMSU Channel 14. Other reanalyses handled this transition in different ways, switching immediately over from the SSU to AMSU in 1998 or assimilating both for an extended period of time. The greatest temperature impacts from this transition occurred above 10hPa. The test runs showed that transitioning immediately from the SSU to the AMSU resulted in warmer temperatures above 2hPa and cooler temperatures from 10-2hPa. Assimilating both SSU and AMSU radiances reduced the respective warming and cooling by about 50%.

Joint SPARC-DA/S-RIP workshop

Quentin Errera presented a first effort in producing a chemical reanalysis of stratospheric composition based on assimilation of MLS and MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) observations for the period between 2007 and 2012. This study uses the Belgian Assimilation System for Chemical ObsErvations (BASCOE) where 13 chemical species are assimilated: O_3, H_2O, CH_4, N_2O, HNO_3, NO_2, N_2O_5, $ClONO_2$, HCl, ClO CFC-11, and CFC-12. While the reanalysis agrees relatively well with independent observations, several issues were pointed out, in particular 'zigzags' in the CH_4 profile in the lower tropical stratosphere coming from the observations as well as temporal inconsistencies resulting from temporal inconsistencies in the observing systems.

Chiaki Kobayashi evaluated the BDC in the Japanese 55-year Reanalysis (JRA-55) family, *i.e.*, JRA-55, JRA-55C (which assimilated conventional observations only; Kobayashi *et al.*, 2014), and JRA-55AMIP (with the same forecast model as JRA-55 and JRA-55C but without data assimilation). She showed that seasonal variations of the JRA-55 BDC compare well with those from ERA-Interim, which was not the case with the previous JRA-25 product. However, the time series of troposphere-stratosphere mass exchange is different; over time the mass exchange increased in JRA-55 and decreased in ERA-Interim. The BDC in the JRA-55AMIP data was found to be weaker than that in either the JRA-55 or the JRA-55C data. Model experiments suggested that improving the gravity wave parameterization so that the forecast model would spontaneously produce a QBO may result in strengthening the BDC.

Zac Lawrence showed a comparison between MERRA and ERA-Interim based on diagnostics related to the formation of polar stratospheric clouds, chlorine activation, and the destruction of stratospheric ozone. Temperature in the winter polar vortex is usually lower in MERRA than in ERA-Interim prior to 2002 and *vice versa* thereafter. This is due to differences in the assimilated observing systems used in both reanalyses. MERRA also exhibits larger regions of cold air, while ERA-Interim exhibits more cold days and larger polar vortices. Will the choice of MERRA or ERA-Interim strongly influence polar processing studies? In the early years (prior to 2002), the answer is yes.

Siddarth Das presented a comparison of *in situ* radiosonde and rocketsonde observations with different reanalyses (MERRA, ERA-40, ERA-Interim, and NCEP-II) over Thumba, India (8.5°N, 76.5°E). Features like the QBO and tropical easterly jet compared well between reanalyses and observations. The zonal winds also agree well up to 30km, however, for the meridional wind agreement is only good below the tropopause. Also comparing several reanalyses (ERA-Interim, MERRA, and JRA-55), **Bernard Legras** focused on the BDC based on age-of-air calculations. Compared to previous generations of reanalyses *(e.g.* ERA-40), agreement with observations is much better. However, in the northern hemisphere reanalyses still disagree and it is not clear how to reduce these differences.

Representing the SPARC temperature trend activity, **Dian Seidel** discussed satellite observations of stratospheric temperature and presented preliminary results of an intercomparison of climate data records (CDRs) from meteorological sounders including MSU (Microwave Sounding Unit) channel-4, three channels of SSU, and four channels of AMSU spanning 1979-present. Despite recent revisions of SSU CDRs motivated by an earlier study (Thompson *et al.*, 2012), differences remain between two versions of the SSU data and among the three versions of MSU data. Empirical orthogonal function analyses revealed significant vertical and latitudinal structure in the main patterns of stratospheric temperature variability, with the polar regions accounting for a very high fraction of interannual variability. For some channels, volcanic signals were also evident and interestingly, long-term trends did not appear to account for much of the variability. Also motivated by the Thompson *et al.* (2012) study, **Cheng-Zhi Zou** presented a recalibration and re-adjustment of the level 1c SSU data, which were affected by a space view anomaly. These revised SSU temperature trends are shown in **Figure 9.**

The end of the session saw four presentations about recent updates being carried out by the different reanalysis centres. **Steven Pawson** discussed the status of MERRA-2 at NASA, which is in production phase and is expected to be released in February 2015. Compared to MERRA, the new version will benefit from modern radiance data types, an update of the SSU data used, the inclusion of temperature and ozone profiles from MLS (from 2004 onwards), as well as various model improvements (see also the contribution of Lawrence Coy above). **David Tan** discussed the future ECMWF reanalysis which will replace ERA-Interim. This reanalysis will benefit from reprocessed observations and an improved model version, both of which are expected to deliver, amongst many things, a better representation of SSWs. **Craig Long** discussed the status of the four NOAA reanalysis efforts: NCEP/NCAR, NCEP/DOE, NCEP/CFSR, and ESRL/20CR. NOAA has also just begun plans to create a new reanalysis as part of its next version of the Climate Forecast System. This reanalysis would be generated in the 2018-2020 timeframe. A new version of 20CR and updates of other the NCEP/NCAR reanalyses are also in the early planning stage. **Yayoi Harada** presented some aspects of the new JRA-55 reanalysis with respect to the older JRA-25 reanalysis. In particular, he showed that JRA-55 reduced the cold bias in the stratosphere and significantly improved temporal consistency compared to JRA-25. The consistency of atmospheric flow in the stratosphere is also improved in terms of the momentum budget. As discussed above, the Japanese Meteorological Agency has also produced two other reanalyses, JRA-55C and JRA-55AMIP, whose data will also soon be available for scientific use.

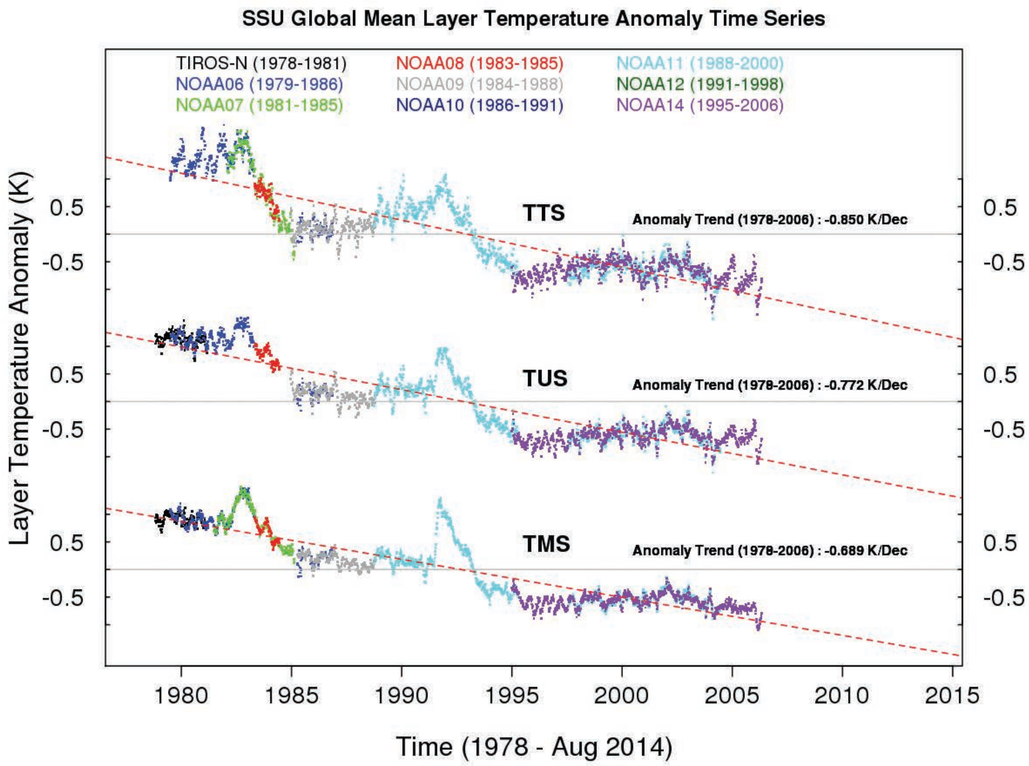


Figure 9: SSU global mean anomaly time series and trends for layer temperatures of mid-stratosphere (channel 1), upper-stratosphere (channel 2), and top-stratosphere (channel 3) after recalibration and adjustment of multiple instrument drifting effects of the level 1c radiances. (Provided by Cheng-Zhi Zou).

Seven posters were also presented during the workshop. **Simon Chabrillat** compared Chemistry Transport Model (CTM) simulations driven by two different reanalyses: MERRA and ERA-Interim. **Young-Ha Kim** compared equatorial stratospheric waves and the QBO momentum budgets of ERA-Interim, MERRA, JRA-55, and CFSR. **Craig Long** displayed two posters comparing these same four reanalyses focused on temperature and zonal wind in the stratosphere. **Takatoshi Sakazaki** compared stratospheric temperature tides between the same four reanalyses as well as NOAA 20CR. In addition to the four above-mentioned reanalyses, **Seok-Woo Son** also considered NCEP-NCAR, NCEP-DOE, JRA-25, and ERA-40, and evaluated their consistency in terms of momentum diagnostics. Finally, **Masakazu Taguchi** compared the interannual variability in northern stratospheric winter using the same eight reanalyses as well as NCEP 20CR.

Report from the S-RIP workshop

At the S-RIP planning meeting held in 2013 (Fujiwara and Jackson, 2013), it was decided that annual S-RIP workshops would be held until 2018, when the final full report is planned for publication. The main purpose of these annual workshops is to discuss progress and current issues facing each chapter of the planned S-RIP report. On day three, **Masatomo Fujiwara** presented an overview of S-RIP and chapter 1 (Introduction) and **David Tan** presented the progress of chapter 2 (Description of the Reanalysis Systems). On day four, **Craig Long** discussed chapter 3 (Climatology and Interannual Variability of Dynamical Variables), **Sean Davis** and **Michaela Hegglin** discussed chapter 4 (Climatology and Interannual Variability of Ozone and Water Vapour), **Thomas Birner** and **Beatriz Monge-Sanz** discussed chapter 5 (Brewer-Dobson Circulation), **Edwin Gerber** discussed chapter 6 (Stratosphere-Troposphere Coupling), **Gloria Manney** and **Cameron Homeyer** discussed chapter 7 (Extra-tropical Upper Troposphere and Lower Stratosphere), and **Jonathon Wright,** on behalf of the chapter leads Susann Tegtmeier and Kirstin Krüger, discussed chapter 8 (Tropical Tropopause Layer). On day five, **James Anstey** discussed chapter 9 (Quasi-Biennial Oscillation and Tropical Variability), **Michelle Santee** discussed chapter 10 (Polar Processes), and **Diane Pendlebury** and **Lynn Harvey** discussed chapter 11 (Upper Stratosphere and Lower Mesosphere). Rapporteurs were assigned for each chapter and they made brief summary presentations at the end of the workshop.

The S-RIP 'Interim' Report, covering the 'basic' chapters (1-4) will be completed and published in 2015. Discussion also focused on the actual procedures in terms of producing the report. It was also agreed that by mid-2015 a zeroth-order draft would be prepared for the 'advanced' chapters (5-11).

Discussion and next workshop

David Jackson officially stepped down as chair of the SPARC DA activity and co-lead of S-RIP in April 2014. Quentin Errera has replaced him as SPARC DA lead while David Tan was approved as new S-RIP co-lead at the workshop (prior to the workshop, Masatomo Fujiwara, the other S-RIP co-lead, had proposed him as candidate). It was also agreed that the next SPARC DA workshop would again be held jointly with the next S-RIP workshop in fall 2015, in coordination with other SPARC-related workshops.

References

Charlton-Perez, A. and D. Jackson, 2012: SNAP: The Stratospheric Network for the Assessment of Predictability. *SPARC Newsletter*, **39**, 40-42.

Fujiwara, M. and D. Jackson, 2013: SPARC Reanalysis Intercomparison Project (S-RIP) Planning Meeting, 29 April–1 May 2013, Exeter, UK. *SPARC Newsletter*, **41**, 52-55.

Hegglin, M. I. *et al.*, 2014: Vertical structure of stratospheric water vapour trends derived from merged satellite data. *Nature Geoscience*, **7**, 768-776, doi:10.1038/ngeo2236.

Kobayashi, C. *et al.*, 2014: Preliminary results of the JRA-55C, an atmospheric reanalysis assimilating conventional observations only. *SOLA*, **10**, 78-82, doi:10.2151/sola.2014-016.

Lefever, K., *et al.*, 2014: Copernicus atmospheric service for stratospheric ozone: validation and intercomparison of four near real-time analyses, 2009–2012. *Atmos. Chem. Phys. Discuss.*, **14**, 12461-12523, doi:10.5194/acpd-14-12461-2014.

Shepherd, T. G. *et al.*, 2014: Reconciliation of halogen-induced ozone loss with the total-column ozone record. *Nature Geoscience*, **7**, 443-449, doi:10.1038/ngeo2155.

Thompson, D. W. *et al.*, 2012: The mystery of recent stratospheric temperature trends. *Nature*, **491**, 692-697, doi:10.1038/nature11579.

Wang, H. *et al.*, 2014: First forecast of a sudden stratospheric warming with a coupled whole-atmosphere/ionosphere model IDEA, *J. Geophys. Res. Space Physics*, **119**, 2079-2089, doi:10.1002/2013JA019481.

Vladimir Ryabinin – SPARC liaison at WCRP Joint Planning Staff: 2002-2015

Vladimir joined the WCRP Joint Planning Staff (JPS) in November 2001 with the primary responsibility of taking care of polar and cryospheric research, in particular the Climate and Cryosphere (CliC) core project that had just been established in 2000. When Roger Newson retired in 2002, Vladimir took over the responsibility of SPARC at the WCRP. Since then, Vladimir has been a vital supporter of SPARC and was integral in helping SPARC evolve into an even better project during his tenure. His warm smile, approachability, and great wisdom, will be missed by the many who had the wonderful opportunity of interacting with him.

Vladimir will be taking up a new position as executive secretary at the UNESCO Intergovernmental Oceanic Commission in Paris as of March 2015. The entire SPARC community thanks Vladimir for all his hard work and friendship and wishes him every success in his new position!

Boram Lee, who before joining the WCRP worked for the Marine Meteorology and Oceanography Programme of the WMO, is the new SPARC liaison. We all look very much forward to working with Boram and wish her all the best for the new beginnings at WCRP!

by Fiona Tummon, SPARC Director

Johannes Staehelin's retirement – a personal view

Professor Johannes Staehelin is retiring after a distinguished scientific career, most recently as Director of the SPARC Office. Johannes is a Zurich man through and through who in his early professional career was involved in the aqueous chemistry of environmental pollutants before switching to gas-phase pollutants and eventually ozone. Johannes joined the Institute of Atmospheric Science at the ETH Zurich in 1988, where one of his initial responsibilities was to take over the interpretation of the Swiss ozone measurements from the great Prof. H.U. Dütsch. These measurements included the Arosa total ozone record, which started in 1926, and it was over these data that our paths crossed since I was in California busy analysing the same measurements. Rather than being a threat to the long-established principle of Swiss neutrality, Johannes's welcoming attitude meant that this resulted in a long, fruitful, and enjoyable scientific collaboration with a number of papers published on the subject of ozone trends, one of his several areas of scientific interest. These were reflected in the various national and international assessments and committees he was involved in, including several with WMO and the International Ozone Commission, following in the footsteps of Prof. Dütsch. These experiences equipped him well for his role as Director of the SPARC Office since its move to Zurich in 2011. I struggle to describe his approach to science - at a dinner during the recent SPARC Scientific Steering Group meeting, I could only manage 'Staehelinesque'. That was immediately understood by those who know him well, but was probably not too helpful to others. On slightly more sober reflection, 'Staehelinesque' probably means 'an odd mixture of enthusiasm, puzzlement, worry about details, and enjoyment of tackling hard problems'. So looking ahead, I hope Johannes has an equally enjoyable retirement, though not fully until 2016, as he will continue in an advisory role until the end of 2015. I am sure the whole SPARC community join me in thanking him for his hard work as director and in wishing him all the best for the future.

Johannes enjoying a good laugh at the recent SPARC SSG meeting held in Granada, Spain

by Neil Harris, SPARC Co-Chair

SPARC meetings

16-18 March
QBO Modelling and Reanalyses Workshop, Victoria, BC, Canada

9-10 April
Temperature Trends - Observed and Modeled Stratospheric Temperature Changes, Victoria, BC, Canada

24 April - 1 May
SSiRC Workshop, Bern, Switzerland

8-10 June
2nd Workshop on Atmospheric Composition and the Asian Summer Monsoon (ACAM), Bangkok, Thailand

24-28 August
SPARC Workshop on Storm Tracks, Grindelwald, Switzerland

5-9 October
CCMI/AeroCom Workshop, Rome, Italy

SPARC-related meetings

23-25 February
Symposium on Coupled Chemistry-Meteorology/Climate Modelling, Geneva, Switzerland

7-11 April
International Conference on Volcanoes, Climate, and Society, Berne, Switzerland

15-26 June
1st WCRP Summer School on Climate Model Development, Hamburg, Germany

22 June - 2 July
26th General Assembly of the International Union of Geodesy and Geophysics, Prague, Czech Republic

7-10 July
International Scientific Conference on Our Common Future Under Climate Change, Paris, France

26-31 July
AGU Chapman Conference on 'The Width of the Tropics: Climate Variations and Their Impacts,
Santa Fe New Mexico, USA

www.sparc-climate.org/meetings/

SPARC going paperless

In an attempt to contribute to a sustainable environment the SPARC Office aims to disseminate this newsletter primarily in its electronic form. Don't hesitate to contact the SPARC Office (office@sparc-climate.org) should you wish to change to an electronic-only newsletter subscription.

SPARC Scientific Steering Group

Co-Chairs
Joan Alexander (USA)
Neil Harris (UK)

Members (2015)
Julie Arblaster (Australia)
Mark Baldwin (UK)
Ed Gerber (USA)
Alexey Karpechko (Finland)

Members (cont.)
Thando Ndarana (South Africa)
Michelle Santee (USA)
Kaoru Sato (Japan)
Adam Scaife (UK)
Hauke Schmidt (Germany)
Martin Schultz (Germany)
Seok-Woo Son (Republic of Korea)
Tianjun Zhou (China)

Ex-Officio Members
Geir Braathen (WMO)
John P. Burrows (COSPAR)
Claire Granier (IGBP)
Marv Geller (SCOSTEP)
Michael J. Kurylo (NDACC)

WCRP liaison
Boram Lee (WMO)

Publication details

Editing
Fiona Tummon

Design/layout
Petra Bratfisch. Carolin Arndt

Print & distribution
ETH Zurich

ISSN 1245-4680

SPARC Office

Director
Fiona Tummon
Project Scientists
Johannes Staehelin
Diane Pendlebury
Communication Officer
Carolin Arndt
Office Manager
Petra Bratfisch

Contact
SPARC Office
c/o ETH Zurich
Institute for Atmospheric and Climate Science (IAC)
Universitaetstrasse 16
CH-8092 Zurich
Switzerland
office@sparc-climate.org