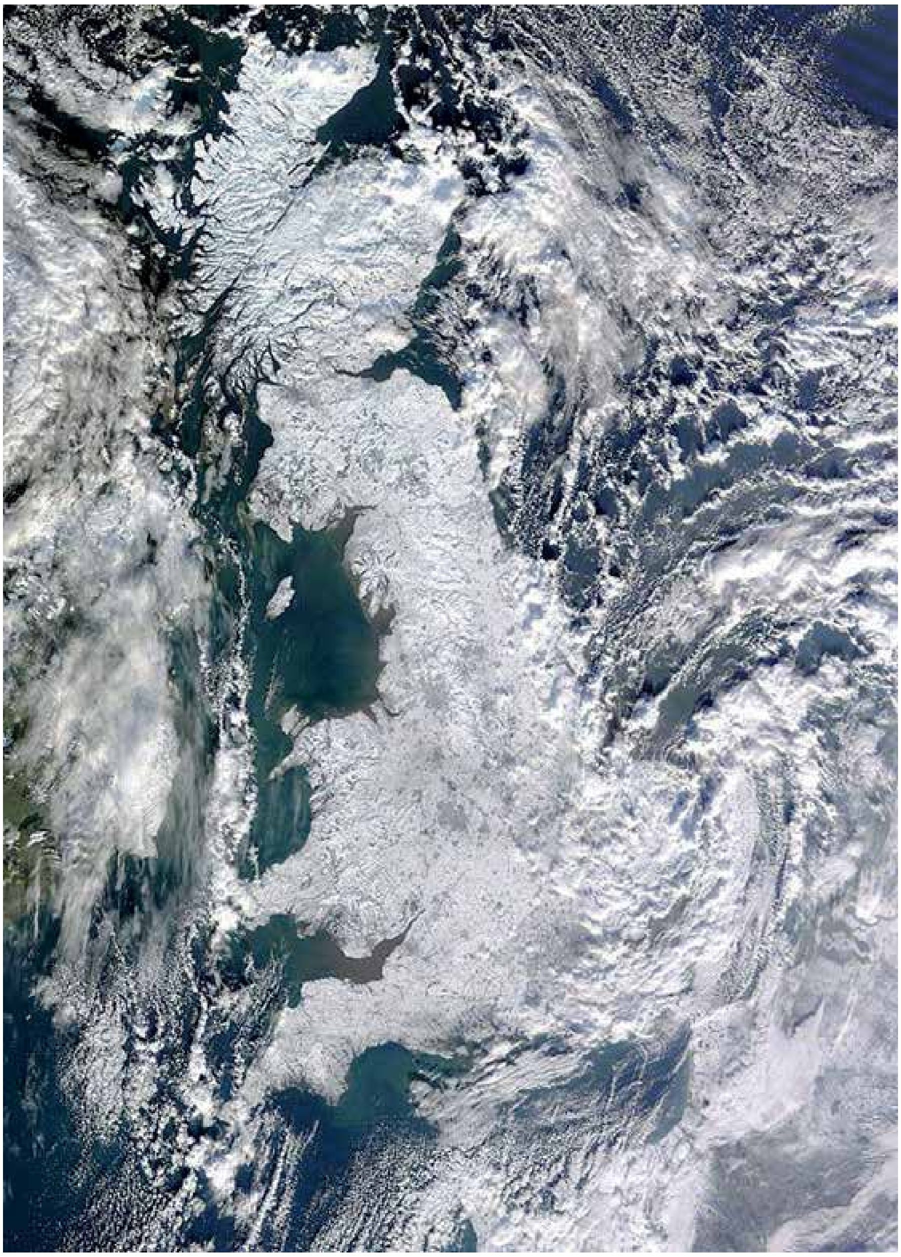
SPARC

Stratosphere-troposphere Processes And their Role in Climate

newsletter n° 47
July 2016

www.sparc-climate.org



Atmospheric blocking events are large-scale patterns in the atmospheric pressure field that are effectively stationary. They can remain in place for several days at a time, causing the areas affected by them to have the same kind of weather for an extended period of time. In the Northern Hemisphere mid-latitudes, areas on the eastern side of blocking anticyclones or under the influence of anomalous flows from colder continental interiors related to blocks can experience severe winters. A SPARC-supported workshop was held in April to discuss recent advances in our understanding of blocking, its impacts and its representation in numerical models. Image courtesy of the NASA MODIS Rapid Response Team.

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WCRP World Climate Research Programme

WMO

UNESCO

IOC

ICSU International Council for Science

Stratospheric Change and its Role for Climate Prediction (SHARP2016)

16-19 February 2016, Berlin, Germany

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The stratospheric response to anthropogenic changes and its feedback on tropospheric climate and weather are of growing interest in climate research and numerical weather prediction. The SHARP-2016 workshop discussed recent progress and future directions in the research on stratospheric change and its implications for climate and weather with focus on four topics:

- Brewer-Dobson circulation
- Stratospheric ozone
- Stratosphere-troposphere coupling
- Stratospheric water vapour.

In combination with the closing event of the six-year German DFG research program 'Stratospheric Change and its Role for Climate Prediction' (SHARP) (Langematz, 2011), the workshop brought together 117 scientists from 16 countries (**Figure 7**) to discuss the progress achieved since the start of the SHARP research group, to present new science in the SHARP research areas, and to discuss future research needs.

The SHARP-2016 workshop was dedicated to Professor Karin Labitzke, head of the Stratospheric Research Group at Freie Universität Berlin from 1970-2000, who passed away on 15 November 2015.

Workshop summary

The opening lecture was given by **Neil Harris**, who presented an overview of the evolving science in SPARC, from its implementation in 1992 to the recent re-orientation towards 'Stratosphere-troposphere Processes And their Role in Climate' in 2014 and new 2016-2020 SPARC Implementation Plan. The following subsections summarize the major topics addressed in the four sessions.

Day 1: Brewer-Dobson Circulation

While Brewer Dobson Circulation (BDC) research has existed since 1949, new aspects have been added or refined in the recent past, such as the separation of a lower and upper stratospheric branch of the BDC, the distinction between the residual circulation (RC) versus the BDC, or the role of mixing for the mean age-of-air (AoA), as summarized in a keynote lecture by **Thomas Birner**. Since the 1990s, modern BDC research has been fostered by climate change and stratospheric ozone depletion. A closer view of the drivers of RC (planetary, synoptic, and gravity waves) and its trends was presented by **Sophie Oberländer-Hayn**, **Felix Bunzel**, and **Peter Hitchcock**. **Hella Garny** found that the robust strengthening of the shallow branch of the BDC in free-running climate models is neither seen in simulations with specified dynamics nor in the ERA-Interim reanalysis, and suggested missing variability in the free-running models as a possible reason. Another question of interest was the relationship between RC and the transport circulation, including two-way mixing. The effects of RC and mixing on stratospheric AoA were discussed (**Felix Plöger**, **Simone Dietmüller**). Interannual variability of AoA due to past volcanic eruptions was addressed in a talk by **Mohamadou Diallo**, while **Paul Konopka** showed that the ENSO anomaly in the mean AoA is of the order ±4 months, mainly due to differences in the RC than eddy mixing. Another focus was on new measurement and analysis methods, such as the AIRCORE technique to measure AoA (**Andreas Engel**), the use of tracer measurements to derive the BDC via the continuity equation (**Thomas von Clarmann**), the use of AoA data in a new theoretical approach to derive RC (**Marianna Linz**), or the application of a 3D BDC analysis to climate model output to show future increased downwelling (~50%) over Northern Europe/West-Siberia (**Axel Gabriel)**. The application of an idealized model was suggested for better validating stratospheric transport in climate models and to help explain discrepancies between models and observations (**Eric Ray**). **Ted Shepherd** addressed the climate impact of past changes in halocarbons in the tropical upper troposphere/lower stratosphere (UTLS) region compared to the effects of CO_2. Halocarbons are an important greenhouse gas at the tropical tropopause, however chemistry-climate model (CCM) simulations showed that the expected radiative warming resulting from an increase in halocarbons is nullified by feedbacks from water vapour and ozone. While the stratospheric column ozone increases with increasing CO_2, it decreases with increasing halocarbons.

Day 2: Stratosphere–Troposphere Coupling

In a keynote lecture **Mark Baldwin** highlighted the role of the stratospheric "wave-driven pump" for stratosphere-troposphere coupling (STC), as it creates potential vorticity anomalies corresponding to weak and strong vortex conditions and moves mass into and out of the polar cap. The North Atlantic Oscillation signal from the stratosphere is self-reinforcing through modifying baroclinic eddies, thus amplifying the stratospheric signal. The use of a simple polar cap pressure diagnostic was suggested to evaluate STC in models. The downward propagation of anomalies after sudden stratospheric warmings (SSWs) was found to be independent of the strength of the SSW, suggesting an active role of the troposphere in the downward propagation (**Theresa Runde**, presented by **Martin Dameris**). **Amanda Maycock** (presented by **Peter Hitchcock**) showed that differences in the Northern Annular Mode signature between displacement and split SSWs are uncertain and dependent on the SSW definition, arguing that knowledge of the magnitude and persistence of stratospheric anomalies is likely to be more useful for predictability than knowledge of the event type. A classification of SSWs according to whether or not wave reflection occurs during the recovery phase of the SSW was introduced, with absorbing SSW types leading to an Arctic Oscillation signal (**Kunihiko Kodera**). Mechanisms for the downward influence of the stratosphere on the tropospheric jet and surface climate were discussed and the roles of interactive chemistry and feedbacks in tropospheric synoptic wave activity emphasized (**Peter Hitchcock**, **Aditi Sheshadri**, **Sabine Haase**). It was also shown in a number of talks that stratospheric ozone is clearly a leading order forcing of the climate system. Using ensemble CCM simulations **Natalia Calvo** found that stratospheric ozone minima have a significant impact on surface climate, and March Arctic ozone could be useful for tropospheric prediction of April and May surface climate in certain regions (**Diane Ivy**). The relevance of ozone in STC was also documented in presentations of stratospheric intrusions in multiple tropopauses (**Irina Petropavlovskikh**), a projected change of stratospheric-tropospheric ozone exchange with increasing greenhouse gases (**Stefanie Meul**), changes in European tropospheric ozone (**Fiona Tummon**), radiative ozone feedback (**Catrin Gellhorn**, **Michael Ponater**), and as a driver of the recent tropical expansion (**Chaim Garfinkel**). Results from a new generation of fully coupled stratosphere-troposphere-ocean models were presented allowing the study of feedbacks between stratospheric change and the oceans (**Blanca Ayarzagüena**, **Nour-Eddine Omrani**, **Rongcai Ren**). Other studies focused on the tropical tropopause layer (TTL), addressing questions such as what can be done to narrow the gap between the observed and modeled TTL and how can a better tropical stratosphere improve tropospheric climate and weather forecasts. Using idealized model experiments, **Edwin Gerber** showed that the TTL is largely controlled by tropical processes with an asymmetric impact of synoptic waves on the TTL annual cycle.

Day 3: Stratospheric Ozone

A major topic in the stratospheric ozone session was the use of long-term ozone datasets to derive robust stratospheric ozone trends. New combined ozone datasets have recently become available, such as the ESA-Climate Change Initiative total ozone climate data record covering the period 1995-2015 (**Melanie Coldewey-Egbers**), and trends from different instruments at Northern Hemisphere mid-latitude stations were presented (**Sophie Godin-Beekmann**). In line with the WMO/UNEP Scientific Assessment of Ozone Depletion 2014, the extended datasets suggest the beginning of a recovery of upper stratospheric ozone (but with low significance), while no significant increase of global total column ozone was reported (keynote lecture by **Wolfgang Steinbrecht**). Confirmation of these results will require continuing long-term high-quality observations and analysis.

Moreover, it is important to assess the stability of long-term ozone profile records. In order to detect ozone trends of 3%/decade due to the decline of ozone depleting substances there are requirements with respect to the stability of individual instruments and the quality of the reference dataset (**Daan Hubert**, **Mark Weber**). Observations of recent changes in stratospheric composition indicate slow decreases of chloroflourocarbons, halons, chlorine, and bromine, confirming the success of the Montreal protocol. An observed increase in HCl in the recent past could be attributed to stratospheric dynamical variability and is not in contradiction to the Montreal Protocol. The atmospheric abundance of the uncontrolled very short-lived substance CH_2Cl_2 is, however, increasing rapidly, and needs to be monitored. The MP has already shown some benefits, since without the Montreal Protocol the March 2011 Arctic ozone loss would have been comparable to Antarctic ozone loss (**Martyn Chipperfield**). Airborne measurements of Br_y in the TTL show good agreement between observations and models, however, the flight-to-flight variability is not captured by models. A new value of Br_y=19.5-22.5ppt was added to the bromine budget for 2013, indicating no trend (**Bodo Werner**). Chemistry-climate simulations show that both ozone depleting substances (ODSs) and greenhouse gases, like CO_2, N_2O, and CH_4 have affected and will further affect the ozone layer (**Wolfgang Steinbrecht**). With declining ODSs, N_2O, and CH_4 will become more important in future. The effect of a future increase in N_2O on ozone depends on the greenhouse gas scenario, with no stratospheric NO_y change expected for the strongest RCP8.5 scenario (**Stefanie Meul**). Decreasing ODSs will lead to higher polar spring total ozone, while a concurrent greenhouse gas increase will enhance this effect due to an increase in the eddy forcing associated with enhanced sea surface temperatures (**Martin Budde).** The role of dynamical variability for ozone was demonstrated for the tropical quasi-biennial oscillation (QBO) that leads to a negative correlation of ozone and temperature with dynamics as the main driver below 30km, while above 30km a positive correlation exists, with photochemistry being the driver (**Toshihiko Hirooka**). The El Niño-Southern Oscillation (ENSO) was shown to be an important factor for regional tropical ozone trends that might be misrepresented in zonal mean data (**Peter Braesicke**).

Figure 7: Participants of the SHARP2016 workshop in Berlin.

Day 4: Stratospheric Water Vapour

While progress has been made in the understanding of processes governing the entry of water vapour into the stratosphere, this understanding is still incomplete (keynote lecture by **Stefan Fueglistaler**). Large-scale transport and temperature seem sufficient to explain the most prominent features of stratospheric water vapour (SWV), with horizontal advection playing an important role, particularly in cold regions, and recent trajectory-based model studies give reasonable answers. Likewise, general circulation models with correct tropopause temperatures simulate reasonable SWV. However, challenges remain regarding the importance of temporal versus spatial temperature variance, the unexplained variability in the observational record, for example the year 2000 water vapour drop, the existence of evidence for the importance of various transport pathways, and the efficiency of cirrus dehydration. A wealth of new observational datasets, also with improved quality have become available from tropical *in situ* measurements (**Holger Vömel**) as well as from satellite measurements (SCIAMACHY, **Katja Weigel**, and MIPAS, **Stefan Lossow**). A systematic analysis of almost all available datasets, performed as part of the SPARC WAVAS-II initiative, has led to a better characterisation of instrumental biases and drifts (**Karen Rosenlof**). A detailed comparison of the Boulder Frost-Point Hygrometer SWV series with satellite, airborne measurements from the MACPEX campaign, and model simulations showed partially excellent agreement, but also problematic periods and local effects (**Dale Hurst**). Using CCM simulations as a transfer standard, **Michaela Hegglin** presented a combination of multiple datasets to study variability on longer time scales than one individual dataset can provide. Comparisons between simulations and observations show qualitative agreement but still differences in quantitative terms.

When laid over the mean 'tape recorder', SWV exhibits tape recorder anomalies due to ENSO, the QBO, or stratospheric major warmings. The latter may lead to an additional dehydration signal of 0.1-0.3ppmv, depending on the phase of the QBO at the tropical tropopause (**Martin Riese**). An indirect effect of decadal solar variability was shown on tropical lower stratospheric water vapour, with a negative correlation of about 25 months after solar maximum (**Gabriele Stiller**). A comparison of water vapour in CCM simulations showed that the cold-point temperatures in models play a crucial role for SWV, largely explaining the spread among models. A multi-model CCM analysis of SWV variability due to the Asian Summer Monsoon, ENSO, and QBO was presented by **Markus Kunze**, and due to the effect of volcanic eruptions by **Patrick Jöckel**. **Sabine Brinkop** also used CCM simulations with specified dynamics to show that sea surface temperatures and related upwelling, as well as the QBO and the synoptic situation contributed to the drop in SWV after the year 2000. To better understand the driving mechanisms of SWV in the models, further diagnostics, *e.g.,* isotopologues, were implemented (**Roland Eichinger**), as well as comprehensive observational datasets for model evaluation. In future, an increase of SWV is projected following a warming of the TTL, however, an increase in convective ice lofted into the stratosphere could also play a role (**Andrew Dessler**), as well as methane oxidation in the upper stratosphere (**Andrea Stenke**).

Reference

Langematz, U. and the SHARP consortium, 2011: Stratospheric Change and its Role for Climate Prediction (SHARP): A contribution to SPARC, *SPARC Newsletter*, **36**, 32-35.

SPARC meetings

12-15 September
WGNE/SPARC Drag Processes Workshop
Reading, UK

26-30 September
SPARC QBO Workshop
Oxford, UK

17-19 October
SPARC DA Workshop
Victoria, BC, Canada

19-21 October
S-RIP 2016 Workshop
Victoria, BC, Canada

31 October - 1 November
SPARC Grand Challenges Workshop
Berlin, Germany

30 November - 3 December
WAVAS II Meeting
Karlsruhe, Germany

Open Call for SPARC SSG Nominations

Submit your nomination for SSG membership through the SPARC website: **www.sparc-climate.org/about/leadership/**

Deadline: 30 September 2016

Summer School on Atmospheric Composition and Dynamics

28 Nov – 3 Dec 2016, La Réunion Island
See **http://lacy.univ-reunion.fr/formation/summer-school** for more details

SPARC-related meetings

30 July – 6 August
41st COSPAR Assembly
Istanbul, Turkey

31 July – 5 August
13th AOGS Annual Meeting
Peking, China

4-9 September
Quadrennial Ozone Symposium
Edinburgh, Scotland

14-16 September
International Symposium on the Whole Atmosphere
Tokyo, Japan

19-23 September
CLIVAR Open Science Conference
Qingdao, China

2-4 November
WGCM Model Hierarchies Workshop
Princeton, USA

12-16 December
AGU Fall Meeting
San Francisco, USA

Find more meetings at: www.sparc-climate.org/meetings

Publication details

Editing
Fiona Tummon

Design/layout
Petra Bratfisch & Fiona Tummon

Print & distribution
ETH Zurich, ISSN 1245-4680

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