SPARC
Stratosphere-troposphere Processes And their Role in Climate

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Image credit: Stefanie Kremser

Butchers Dam in Otago, New Zealand with snowy hills in the background. After a long time of no face-to-face meetings, SPARC activites are back to organising and participating in workshops (see workshop reports on page 23 to 33). SPARC is also celebrating its 30th anniversary and therefore we included a very special personal note from one of SPARC's first co-chairs - Marie-Lise Chanin (page 8) as well as some reflections from former SPARC co-chairs. This issue also includes a summary of the SPARC SSG meeting which was held in January 2022. Happy reading!

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WCRP World Climate Research Programme
World Meteorological Organization
United Nations Educational, Scientific and Cultural Organization
Intergovernmental Oceanographic Commission
International Science Council

29th SPARC Scientific Steering Group Meeting

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The 29th SPARC Scientific Steering Group (SSG) meeting took place in January 2022 and was held online over three days; a 3-hour session per day. Despite the different time zones and a very early morning for some, the meeting was well attended, and great discussions ensued.

- The first session took place on the 11th January and focused on the achievements and progress reports delivered by each SPARC activity. All activity leads were asked to present on their 2021 activity highlights, any emerging issues, and their focus in the coming year.
- The second session was held on the 18th January and included presentations by the World Climate Research Programme (WCRP), the WCRP Lighthouse Activities (LHAs), and their two new Core Projects (CP). Discussions focused on how SPARC can best collaborate and interact with these new LHAs and CPs, giving rise to several ideas. Each LHA and the two new CPs had representatives at the meeting, who are involved in both SPARC and the LHAs and CPs. Another key topic of the second session was the new SPARC strategy that has been developed over the last few months, and how it best fits into WCRP's new structure and its LHAs and CPs.
- The third and final session of the SPARC SSG meeting took place on the 21st January and included a presentation about the organisation of the 7th SPARC General Assembly. The main part of the final session was dedicated to continued discussions, Q&A, and feedback on the new SPARC strategy. The second half of the meeting was a closed SSG meeting where new SSG member nominations, events for the 30th Anniversary of SPARC, and general SPARC tasks were discussed.

Activity highlights

Unsurprisingly, the world-wide pandemic has hampered progress in many SPARC activities and has led to the cancellation of many in-person meetings/workshops. Despite this, all activities were able to report on highlights and progresses, and online meetings have instead been held, where possible. After two years of pandemic-life, everyone is keen to attend in-person meetings again, so some activities have started to plan face-to-face meetings/workshops for 2022 and 2023 (see SPARC calendar). A selection of activity highlights is presented below.

The *DAWG* (Data Assimilation Working Group; **Quentin Errera**) activity was completed in 2021. In their final presentation they reported that CAIRT (Changing-Atmosphere InfraRed Tomography Explorer, a whole-atmosphere infra-red limb imaging satellite instrument) has been selected by ESA as one of four candidates that could potentially be put onto a satellite for the upcoming Earth Explorer 11 mission in 2031/2032. The co-chairs thanked Quentin Errera and the DAWG team for all their hard work and commitments over the past few years. Other SPARC activities should discuss how best to include DAWG topics, such as the chemical data assimilation, into their activities.

FISAPS (Fine Scale Atmospheric Processes and Structures, **Marvin Geller**) is continuing to promote and encourage the use of their global high vertical-resolution radiosonde data set (HVRRD) in other SPARC and WCRP activities. This data set is publicly available (SPARC website).

A second overview paper is being developed as part of the *TUNER* (Towards Unified Error Reporting, **Nathaniel Livesey**) activity, as a follow-on from their first overview paper (von Clarmann *et al.*, 2020) which provided a guide on common methodological understanding of error reporting for data providers. This new paper is for data users and is a guideline on how to use the diagnostic metadata provided by the instrument groups correctly.

The *S-RIP* (SPARC– Reanalysis Intercomparison Project; **Lesley Gray**) activity recently published the S-RIP final report (SPARC, 2022a). S-RIP encourages users to use this report as the main reference point for reanalysis data sets. With the publication of this report, Phase 1 of S-RIP has been completed and planning for Phase 2 is underway. Before Phase 2 commences, a new leadership team and contributors need to be found.

One of the main highlights of the *ATC* (Atmospheric Temperature Changes and their Drivers; **Andrea Steiner**) activity was their contribution to the [Sixth Assessment Report of the IPCC] (International Panel on Climate Change, Chapters 1, 2 and 7). Their main findings on upper-air trends were summarised in the executive summary of Chapter 2. ATC is interested in getting involved in the "Explaining and Predicting Earth System Change" WCRP LHA and the ESMO CP as there are clear links between the work done under ATC and the proposed work in the new CP and LHA. After the ATC side-meeting at the TRENDS workshop in Finland (30th May – 3rd June 2022) ATC will appoint a new co-lead and refresh their SSG membership.

Contributing to the WMO/UNEP ozone assessment 2022 (Chapter 3) is one of the main highlights of the *LOTUS* (Long-term Ozone Trends and Uncertainties in the Stratosphere; **Daan Hubert**) activity. The LOTUS-2 ozone profile data set was extended to 2020 and additional satellite data were incorporated. Furthermore, ozone sonde data were homogenized (Petropavlovskikh *et al.*, 2022). The LOTUS-2 activity will be wrapped up in 2022, which initiated discussions of whether LOTUS will be continued as a SPARC activity. LOTUS was planning to discuss potential future science topics at the TRENDS workshop in June 2022.

From 22nd June to 1st July 2021 *ACAM* (Atmospheric Composition and the Asian Monsoon; **Hans Schlager**) held its 4th ACAM training school virtually, hosted by EUMETSAT, Germany. The school included 30 early career scientists and graduate students from 14 countries selected out of 81 applications. The focus of the training school was "Satellite Observations and Analysis of Atmospheric Chemistry and Aerosols in the Asian Monsoon region". A summary about the main outcomes was presented in the SPARC Newsletter N°. 58 (SPARC, 2020b). The 5th ACAM workshop and training school are planned for late 2022 in Kathmandu, Nepal. An ACAM-related field campaign, ACCLIP (Asian Summer Monsoon Chemical and Climate Impact Project), will take place in the Republic of Korea in boreal summer 2022.

An infrastructure to support data submission was developed by the *CCMi* (Chemistry Climate Model initiative; **David Plummer**) activity, to ensure (i) modelling groups produce their data in a consistent manner, and (ii) data can be uploaded to CEDA Archive (Centre for Environmental Data Analysis). Output from 8 models (refD1) and 3 models (refD2) have already been submitted to the archive and CCMi continues to work on getting more modelling groups to also submit their output. Another highlight was the contribution of the updated ozone recovery projections to the 2022 WMO/UNEP Ozone Assessment Report. In 2022, CCMi will work on writing a set of model assessment papers to update the CCMVal-2 assessment and CCMi is currently looking for interested parties who would like to lead one of these assessment papers. Whether or not earlier model data are to be included in these papers is still subject to discussion.

Three review papers published in 2021(Haynes *et al.*, 2021; Hitchman *et al.*, 2021; Martin *et al.*, 2021) are the main highlights to be reported on by the *SATIO-TCS* (Stratospheric And Tropospheric Influences On Tropical Convective Systems; **Shigeo Yoden**) activity. They pointed out that the SATIO-TCS community is quite small and so would like to connect to other communities where TSTC (tropical S-T coupling) is not a central topic but important. This could potentially be achieved by organising a workshop or round table discussions with people from other SPARC activities such as QBOi, DynVar, CCMI, SNAP, S-RIP, ACM and others from outside SPARC.

DynVar (Dynamics and Variability Model Intercomparison Project; **Alexey Karpechko**) promotes the use of the DynVarMIP diagnostics which is a part of the CMIP6 database. These diagnostics are crucial for understanding stratosphere-troposphere dynamics and their response to climate change, and they created a dedicated website for DynVarMIP. Two community papers using the DynVarMIP diagnostics have been published: Ayarzagüena et al. (2020), who addressed future changes in sudden stratospheric warmings, and Abalos et al. (2021), who described the response of the Brewer-Dobson circulation to global warming as simulated by CMIP6 models. Furthermore, the activity encourages the use of simplified models and more theoretical approaches to improve our understanding of two-way stratosphere-troposphere coupling.

The joint *Gravity Waves* (**Riwal Plougonven**) and QBOi (Quasi Biennial Oscillation initiative; **Scott Osprey**) webinars in 2021 were well attended. The online mini workshops were also used to design phase-2 nudging experiments for the QBOi activity. A protocol for QBOi Phase-2 experiments will be developed and published in 2022. QBOi Phase-1 experiments are now all published in a QJRMS Special Section on QBO modelling. In lieu of the QBO@60 workshop in July 2021, an online seminar took place on 6th July 2021 that featured two invited talks celebrating the discovery of the QBO (recordings can be found on the SPARC website).

SNAP (Stratospheric Network for the Assessment of

Predictability; **Chaim Garfinkel**) would like a strong endorsement and support from WCRP for the S2S project to be continued beyond 2023 (when current funding will end). The activity published in the S2S JGR special issue. Furthermore, a paper on the experimental protocol is in development and to be submitted in 2022.

WCRP update

Hindumathi Palanisamy from the WCRP Secretariat presented an update on the WCRP strategic plan in the second session of the SSG meeting. The new WCRP strategy was approved and WCRP is now in the implementation phase. The implementation plan will remain fluid and will adapt along the way based on the objectives and priorities of the strategic plan. The WCRP structure was also modernised to accommodate the new strategic plan. The WCRP secretariat provides the link between the WCRP Joint Scientific Committee (JSC) and the various groups (such as CPs and LHAs), and will work closely with all the international project offices. Compared with the new structure presented in the SPARC Newsletter N°56 (SPARC, 2021), WCRP now includes two additional core projects: (i) Earth System Modelling and Observations (ESMO), which will replace the WCRP modelling and advisory councils as well as WMAC and WDAC; and (ii) Regional Information for Society (RIfS), which was launched recently and will now include Coordinated Regional Downscaling EXperiments (CORDEX) and the Working Group on Regional Climate (WGRC). Also, a number of WCRP Grand Challenges, which will end in 2022, will transition into the new LHAs or CPs.

JSC acknowledges the importance of face-to-face meetings and these are encouraged by WCRP. As a result, WCRP approved additional requests to fund travel to the SPARC GA in October. However, cognisant of the environmental impact, WCRP encourages CPs to propose plans and ideas for new ways of working/meeting together, as well as different ways to make use of the unspent funding for 2022. They welcome any ideas on other means/models for meeting virtually. This aligns with WCRP's goal to reduce travel by 50% from what it had been before COVID.

The new SPARC strategy

The SPARC strategy Task Team, led by **Amanda Maycock**, aimed to develop the new SPARC strategy in an objective way, starting by broadly thinking about SPARC's role within the new WCRP structure. Amanda pointed out that the word 'atmosphere' does not appear on the list of new WCRP core projects - interesting given that SPARC is seen as the home for atmospheric science. This raises the question of whether SPARC is still the right name for a WCRP core project that is about atmospheric science. SPARC seems to be still perceived as stratospheric-focused, despite the name change in 2012/2013 (StPARC). SPARC must therefore broaden its remit to achieve the objective of being the home for atmospheric science within WCRP and to that end, SPARC needs to consider how best to provide value and contribute to existing international activities (CPs, LHAs, MIPs, *etc.*).

The new strategy is designed to increase SPARC's visibility in the science community. For example, WCRP and WMO noted that SPARC does not promote its achievements very loudly. This can be improved, given that SPARC is already contributing to the WMO/UNEP Ozone Assessments, Model Intercomparison Projects, and IPCC. SPARC needs to proactively connect and collaborate with the LHAs and other CPs. Contributing to various ways to better understand atmospheric processes is still desired, but in future the role of the atmosphere in its entirety should be the clear focus. The proposed new structure intends to increase communication both within SPARC and externally, to identify opportunities, encourage collaboration amongst activities and increase the visibility of SPARC science globally. A priority of the new strategy is to retain the strong community that SPARC has established, while recognising the emergence of new science priorities within WCRP and facilitating the community to address these science challenges.

General discussion

The general discussion focused on how best to foster collaboration between SPARC and the new LHAs and CPs. It has been noted that the LHAs and new CPs do not include chemistry climate models nor work to be done for the WMO ozone assessment. Therefore, the question of whether these topics can be included in the new WCRP activities was raised, as they would then also provide a strong link with SPARC. Also, it was stated that the position of SPARC on the assessment on composition, climate and air quality, or whether SPARC is independent, is unclear. The participants of the discussion agreed that it seems there are a lot of linkages to other WCRP activities, but no obvious collaboration exists and it is about knowing how best to get involved.

The new SPARC strategy was discussed in detail and four categories of questions arose from the SPARC strategy presentation in the second session of the meeting:

1. Overall scope: Comments and questions were raised

about the emphasis on 'atmosphere' or 'whole atmosphere', with a possible extension to troposphere.

2. More specific panels: The tasks of the proposed panels were discussed, and there were concerns the chemistry and climate panels were not emphasised enough in the proposed structure.
3. Activity grouping under the thematic panels: It was highlighted that individual SPARC activities could belong to multiple themes.
4. External collaborations: SPARC does a lot of relevant science and provides data to different international panel activities, such as IPCC. However, this is not visible, which needs to be changed. The hope is that the new 'Outreach Panel' that is part of the new strategy will promote SPARC's work to other groups and communities residing outside of SPARC.

In the closed SSG session in the third session of the meeting, nominations to the Steering Group for the term starting in January 2023 were discussed. Gufran Beig and Harry Handon are finishing their terms in 2022 and therefore, two new members are needed, and their names have been put forward to the JSC. The SSG membership of Nathaniel Livesey and Wen Chen were proposed to be extended for another two years. For new SSG nominations, WCRP wants to see diversity in the group. Currently, SPARC SSG has a good gender balance and geographical distribution, but expertise gaps within SPARC and in the new SPARC strategy should also not be forgotten.

News from the SPARC IPO

This year marks the 30th anniversary of SPARC. Over the last 30 years, SPARC has evolved into a major international research coordination hub for atmospheric sciences, with the primary goal to facilitate research that improves our understanding of atmospheric processes and their role in climate. SPARC's initial focus was on stratospheric science linked to ozone depletion but has expanded to cover the whole atmosphere including the coupled troposphere-stratosphere system and impacts on surface climate. SPARC is particularly recognised for its lively scientific community.

To celebrate SPARC's achievements over the last three decades, SPARC hosts a series of online webinars, leading up to the grand SPARC General Assembly in October 2022. The first two webinars were well attended with more than 200 participants and their recordings are available from the SPARC website. The final webinar will take place in September 2022 and we will advertise the event widely once the details have been finalised.
In addition to the webinar series, we also include a personal reflection of SPARC by Marie-Lise Chanin (SPARC co-chair 1992-2000) in this Newsletter (page 8), and we asked all former co-chairs of SPARC, what their personal SPARC highlights were or any fun SPARC memories they would like to share (see page 10 for their quotes!). There is lots to be proud of and SPARC has formed an incredibly supportive community. Let's keep that going for the next 30 years and more.

Other than that, the IPO will focus on the preparation of the SPARC General Assembly and will support the organising committees as much as possible. We will work with Amanda to finalise the SPARC strategy, and as always, will support the SPARC co-chairs and SPARC activities as much as we can.

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Personal reflections on the outlook for SPARC

A major milestone for SPARC is that this year marks our 30th anniversary. In this time, SPARC has evolved into a major international research coordination hub for atmospheric sciences, with the primary goal to facilitate research that improves the understanding of atmospheric processes and their role in climate. To celebrate SPARC's achievements, we organized a series of anniversary webinars. The first speaker, introduced by founding SPARC co-chair Marie-Lise Chanin, was Susan Solomon. She gave a fascinating talk titled "Evolving challenges in Stratospheric Processes and their Role in Climate". The second speaker was Ted Shepherd who covered dynamics and philosophy in a talk titled "Understanding the role of atmospheric circulation in climate variability and change", and was introduced by former SPARC co-chair M. Joan Alexander. The third and final webinar in September is currently in the planning stages, but look out for an announcement in the near future.

During the last two years, there has been much discussion on the future direction of SPARC. The goal is to ensure SPARC retains its position at the forefront of atmospheric science research within the ambitious new WCRP strategy. With the climate being a large interconnected system, understanding atmospheric processes requires close interactions with all other WCRP core projects, including the two new projects Earth System Modelling and Observations (ESMO) and Regional Information for Society (RIfS), and the new Lighthouse Activities. At present, the first-order draft of SPARC strategy is circulating among the task team and SPARC SSG members. Expect to see more details at the General Assembly and in the first newsletter of 2023. Although there may be some changes to the overall organization, SPARC science will remain community driven.

One major difference for SPARC this year is that Neil Harris is no longer at the helm after over 7 years as SPARC co-chair, although we still hope to tap his expertise from time to time. The acting SPARC director is Stefanie Kremser, who has been doing a wonderful job over the last year stepping in for Mareike Heckl while taking family leave. And SPARC office manager Sabrina Zechlau also plays a large role keeping tabs on everything SPARC related. One major headache is simply organizing meetings taking into account the 5 time zones represented. This was also an issue for the January SSG meeting, with even more time zones to take into account. We greatly appreciate Stefanie and Sabrina's ability to keep us all on schedule.

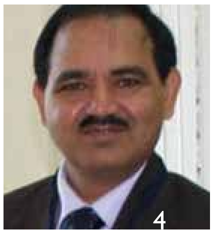
Over the past few months, we have seen the return of in-person conferences and workshops, many of them having a hybrid component; SPARC activities were also holding workshops and side meetings (see workshop reports in this issue) after a 2-year delay. In October, we will have the 7th SPARC General Assembly employing a new multi-hub (Reading UK, Boulder, US and Qingdao, China) hybrid format. The ambitious programme is being led by the Scientific Organising Committee chair, Andrew Charlton-Perez. The goal of the multi-hub format is to retain the face-to-face element and enable international networking, but also reduce the carbon footprint of the meeting. It will involve two hubs taking part in live oral and poster sessions at any one time with an online component available for those who can't travel. We hope to see many of you there.

SPARC co-chairs Seok-Woo Son, Amanda Maycock and Karen Rosenlof

SPARC Scientific Steering Group 2022

We would like to welcome Prof. Wenshou Tian (Lanzhou University, China) and Sophie Szopa (Laboratoire des Sciences du Climat et de l'Environnement, France), who joined the SPARC SSG in January 2022.

Wenshou's expertise on stratospheric chemistry and climate interactions as well as stratosphere-troposphere coupling and Sophie's expertise on tropospheric chemistry will be very valuable to the SSG and SPARC and we look forward working with them over the next 4 years.



	SPARC Co-Chars	
1	Seok-Woo Son (Republic of Korea)	Seoul National University
2	Amanda Maycock (UK)	University of Leads
3	Karen Rosenlof (USA)	National Oceanic and Atmospheric Administration (NOAA); Earth Systems Research Laboratory (ESRL)
	SPARC SSG members	
4	Gufran Beig (India)	Indian Institute of Tropical Meteorology
5	Andrea Carril (Argentina)	Center for Atmosphere and Ocean Research (CIMA/CONICET-UBA), Ciudad Universitaria
6	Wen Chen (China)	Institute of Atmospheric Physics, Chinese Academy of Science
7	Nili Harnik (Israel)	Tel Aviv University
8	Harry Hendon (Australia)	Bureau of Meteorology
9	Takeshi Horinouchi (Japan)	Hokkaido University
10	Nathaniel Livesey (USA)	NASA Jet Propulsion Laboratory
11	Michael Prather (USA)	Department of Earth System Science University of California
12	Viktoria Sofieva (Finland)	Finnish Meteorological Institute
13	Sophie Szopa (France)	Laboratoire des Sciences du Climat et de l'Environnement
14	Wenshou Tian (China)	Lanzhou University
15	Donald Wuebbles (USA)	University of Illinois

Table 1: *Current SPARC Scientiffic Stering Group (SSG) Members*

My first souvenirs of SPARC

Marie-Lise Chanin

LATMOS IPSL

My involvement with SPARC started much before the project even had a name, at least a decade before. To create a new project requires many years of efforts before it can emerge from a dream to reality! The issue of the ozone depletion had obviously raised an enormous interest in our community since the mid 70's, and even more after the discovery of the ozone hole in 1984. The community involved was formed by scientists from above and below the ozone region, either working in the mesosphere or in the stratosphere. Part of this community had been involved in the Middle Atmospheric Programme (MAP). What some of us felt strongly was to demonstrate to the climate community the existence of the numerous interactions between the stratosphere and the troposphere and the role that stratospheric processes could play in climate, beside the immediate consequences of the ozone depletion.

The main question was therefore to have the stratosphere included into one of the two main climate programmes which existed at the end of the 80s. The World Climate Research Programme (WCRP) had been established to investigate the physical processes important in the climate system and the International Geosphere-Biosphere Programme (IGBP) was created to study the interactive physical, chemical, and biological processes that regulate the Earth System. But stratospheric processes were not mentioned in either of them.

Finding a home for SPARC science

As I was a member of the first scientific committee of the IGBP, which was established in 1986, I was well placed to see the importance of including the stratosphere into this new and long-term programme. Tropospheric chemistry was considered to be part of IGBP through International Global Atmospheric Chemistry (IGAC) and the idea to include the stratosphere was seen as a possibility. I had put forward a project called "Stratospheric Change and the Penetration of UV-B Radiation", considering ozone depletion and its possible effect on the biosphere, which led to a first proposal in 1989. But it did not go through, even with the strong support of Paul Crutzen who was also a member of the IGBP committee.

It was only then that I thought of having it included into WCRP which had been established in 1980 to investigate the physical processes important in the climate system and was essentially run by physicists. But accepting a stratospheric project was considered as a threat to the "pure scientific essence" of the whole enterprise because of the chemistry which will disturb that pure world of physics. And it's only after a lot of discussions that SPARC was accepted as a WCRP Project in 1992. I have to say that I had to convince the Director of the programme who at that time happened to be a close colleague of mine, Pierre Morel. But Pierre only respected hard science, which for him meant mathematics and physics. But I succeeded to convince him and the successive Directors of WCRP said they never regretted this decision. The proof is that SPARC is still after 30 years one of WCRP core projects. Today where inter-disciplinarity is encouraged in all global change issues, it is difficult to imagine that the introduction of chemistry in the fortress of physics of WCRP was such a revolution!

A group of scientists led by Marvin Geller and myself who had been working together in the MAP Programme met for the first time in Carqueiranne in summer 1992 to define what SPARC will be. I remember the enthusiasm that SPARC raised when it was at last accepted. The first Scientific Steering Group (SSG)

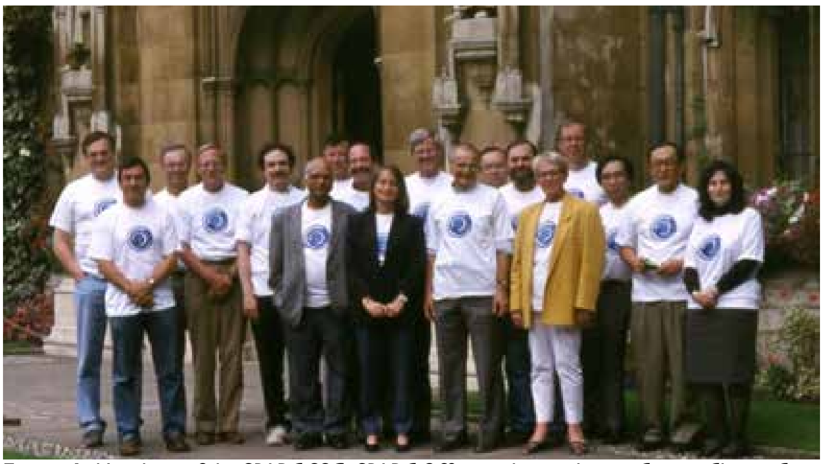


Figure 1: *Members of the SPARC SSG, SPARC Office and attendees in Corpus Christi, Cambridge, UK, September 1993. From left to right: I. Isaksen, J. Pyle, J. Gille, G. Reid, J. Kaye, S. Chandra, R. Newson, M. Geller, M.-C Torre, J. Malhman, D. Ehhalt, V. Khatattov, E.D.Fabo, M.-L. Chanin, P. Simon, Y. Matsuno, H. Tanaka, S. Solomon. Reprint from SPARC, 1993b.*

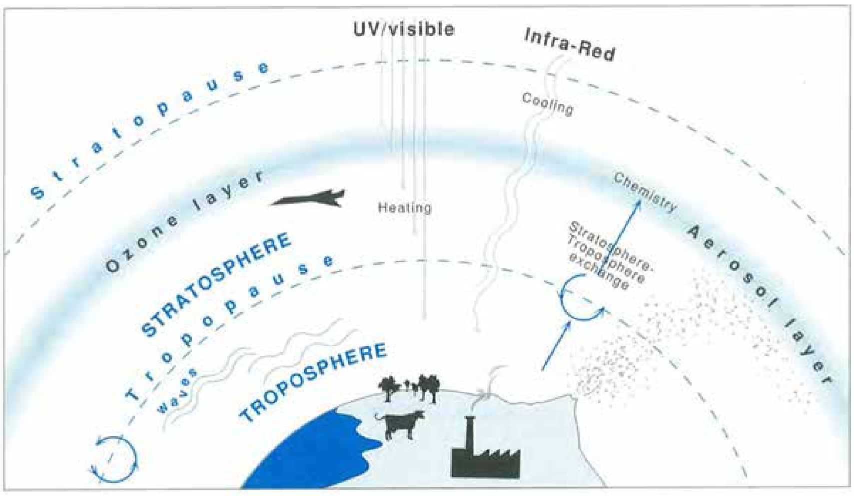


Figure 2: *Scematic showing processes affecting the troposphere - stratosphere system. Reprint SPARC, 1993a.*

members are shown in Figure 1, all wearing a SPARC T-shirt at the first SSG meeting which was held in Corpus Christi College in Cambridge in 1993!

Defining SPARC science and topics

Since the beginning, the two co-chairs, Marvin Geller and myself as well as the SSG members, were very careful not to include topics in SPARC which were already well taken care of by other existing programmes. That meant essentially that we established strong links and good relationships with the national or international "ozone depletion" programmes, as for example the Ozone Commission of the International Association of Meteorology and Atmospheric Sciences (IAMAS), but without interfering with them. This approach worked very well, thanks to a few key people, who recognised that SPARC was not a threat but a complement to their activity. Thus, SPARC focused on understanding stratospheric changes, which are caused either by human activities or by natural variations and how such changes can affect climate.

It would be ambitious to try to summarize here 30 years of SPARC. The number of activities and of scientists involved increased very fast and, as a good example, one can look at the size and content of the SPARC newsletters.

I would like to recall the first initiatives conducted by the SPARC SSG, such as the assessments of our current knowledge of key quantities (temperature, ozone, water vapour and aerosols) and to establish a climatology of the stratosphere. They have been essential to place SPARC in the position to play an important role in the successive World Meteorological Organization – United Nations Environment Programme (WMO-UNEP) ozone Assessments and later in the Intergovernmental Panel on Climate Change (IPCC) Assessments.

It's a pleasure for me to see that some of them are still among the regular work of the actual SPARC project as the assessment of trends in temperature, ozone, water vapor, *etc*. We also picked up topics which later became hot subjects: such as "solar forcing of climate" a topic which was considered as sulphurous at the time, and which has become a real subject of research for the community. The role of the Arctic Oscillation and the North Atlantic Oscillation in the dynamical coupling of the stratosphere and troposphere has shown to be important for the predictability of changes in the troposphere. I should not forget also the role played by gravity waves in the coupling between the different layers of the atmosphere. I also remember the strong pressure we put on IGBP to cooperate on chemistry-climate interactions between SPARC and IGAC.

When remembering the names of all the scientists who gave their time and talents to make SPARC successful, I feel very grateful to all of them. SPARC owes them its successes and its excellent reputation in the WCRP community and I wish to thank them. As Director of the Office for the first 12 years, I don't remember to have experimented refusal of participation from anyone, whether to write articles or organise meetings for SPARC, even from the busiest ones. The most important character of all this period is the wonderful feeling of forming a large family enjoying to work together. This was the best reward that one can have when devoting one's energy to the success of a project. legend of the second one:

SPARC, in the first newsletter was presented as in the schematic shown in Figure 2, focused on understanding stratospheric changes which are caused by human activities and natural variations and how such changes can affect the climate and as a consequence the biosphere.

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SPARC, 1993b: SPARC Newsletter No. 2, December 1993, 8 pp., available at http://www.sparc-climate.org/publications/newsletter.

What do former co-chairs have to say about SPARC?

Marvin Geller (co-chair 1992 – 2002)

"When SPARC began, we anticipated that excellent science would be achieved, but perhaps our most gratifying outcome was the creation of a community of scientists who valued their personal and scientific relationships. What has resulted is a precious SPARC community that ranges from older folks like me to the younger scientists who will inherit the future."

Alan O'Neill (co-chair 2001 – 2006)

"What better reason for having a SPARC than this: that it got its community to do very important collaborative science that otherwise would not have been done? And what greater privilege for a former co-chair like me than to bask in its reflected glory!"

Ted Shepherd (co-chair 2007 – 2012)

"I measure the success of SPARC by two things: first, SPARC has always kept its eye on the ball and focused on where it can make a difference; and second, pretty much everybody working in the SPARC area of science feels that SPARC is their home, so it is a true community."

Greg Bodeker (co-chair 2012 – 2014)

"SPARC, as a major cog in the international scientific research machine, has created global collaborations whose true value will likely not be fully realised for decades to come. It has facilitated research and coordination essential to addressing one of the biggest challenges faced by our planet to date. My involvement in SPARC, and the international collaborations supported by it, has certainly been a highlight of my own research career. I wish SPARC all the best for the next 30 years."

Neil Harris (co-chair 2014 – 2021)

"Doing cutting edge science in a friendly community."

A.R. Ravishankara (co-chair 2003 – 2006)

"SPARC, since its inception led by two competent founding scientists, has been a forward-looking organization of scientists for scientists to advance our science and address societal issues. It has provided invaluable studies, workshops that produced seminal paradigm-shifting papers, and assessments that have benefited our science and society. Even though SPARC started with an emphasis on atmospheric dynamics, it quickly embraced and enhanced chemistry within the organization. I was the first "chemist" to co-chair SPARC! Personally, SPARC allowed me to grow scientifically and interact with many exceptional scientists. Being a co-Chair with Alan O'Neill was my privilege. SPARC workshops and the Assemblies were, and continue to be, venues for honing our science and paving the way for discoveries and enabling the synthesis of information."

CLIVAR/GEWEX Monsoons Panel and its Activities

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Background

Rainfall received from monsoons is the only source of life and livelihood for more than half of the global population. Population in the monsoon regions mainly depends on rainfed agriculture. Three major monsoon regions over the globe undergo a seasonal shift in prevailing circulation (Asia, Australia, Africa, and the Americas). The term "monsoon" refers to a seasonal transition of regimes in atmospheric circulation and precipitation in response to the annual cycle of solar insolation and the distribution of moist static energy. The global monsoon is defined as the area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm/day (IPCC, 2021). Figure 3, reproduced from IPCC (2021), provides a schematic view of the spread of global and regional monsoons around the world.

Asian monsoon, particularly the South Asian monsoon, is one of the widely researched areas leading to a better understanding of some of the associated driving mechanisms as outlined below. The fundamental driving force for the Indian summer monsoon is the differential solar heating of the land and the surrounding oceans during the spring season that establishes the land-sea temperature gradient and helps transport moisture from oceans to the monsoon regions and rains out there. As the season matures, latent heat released by convection above the land surface drives the transport of additional moisture from the surrounding oceans. Rainfall associated with monsoons is a reliable source of fresh water with relatively small year-to-year variations; however, in regions where monsoons contribute to almost the entire annual rainfall, even slight variations can lead to substantial socio-economic hardship. Occasionally, tropical-extratropical interactions modulate monsoonal circulation and precipitation. In addition to year-to-year variations, the monsoons also undergo variations within the season, popularly known as active-break cycles; during the active cycle, abundant rainfall is received, and during a break, little or no rain is observed. The period of occurrence of these cycles is about 20 to 50 days. Year-to-year variability of monsoons occurs primarily due to the El Niño Southern Oscillation. Other drivers include the Indian Ocean dipole and Atlantic zonal modes. Similar mechanisms may also play an essential role in other monsoon regions. However, a detailed study is required to identify the similarities and differences. There is mounting evidence that the stratospheric quasi-biannual oscillation (QBO) plays a role in modulating circulation and precipitation in some monsoon regions. Additionally, all monsoons exhibit variations on multi-year-to-centennial timescales.

The genesis of Monsoons Panel

The WCRP has a longstanding focus on the monsoons, essentially to improve the prediction of monsoon variations to help reduce the risks associated with extreme events during monsoon season. The skill of predicting monsoon year-to-year variations is moderate in many models. The lead time for making reliable active-break cycle predictions during monsoon seasons is up to 20 days. These prediction skills are much better than the earlier skills from previous generation models. All this was possible due to the concerted efforts by scientists worldwide who have significantly contributed to improving the representation of the monsoon in the numerical models used operationally by meteorological services across the globe.

Progress in our scientific understanding of mon-

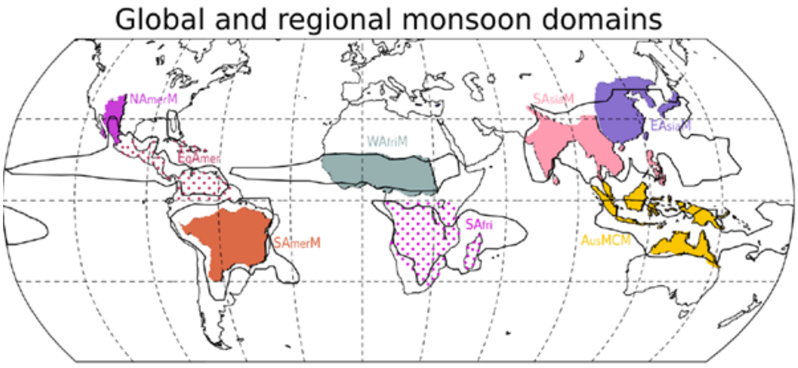

Figure 3: *Global (black contour) and regional monsoons (colour shaded) domains. The global monsoon (GM) is defined as the area with a local summer-minus-winter precipitation rate exceeding 2.5 mm day^{-1}. The regional monsoon domains are defined based on published literature and expert judgement and accounting for the fact that the climatological summer monsoon rainy season varies across the individual regions (Source: IPCC, 2021).*

soons will benefit from the interaction of individuals and groups studying these various regions. CLIVAR (Climate and Ocean: Variability, Predictability and Change) research into ocean-atmosphere interaction and the role of slowly varying modes that lend predictability to the monsoons are of direct relevance to the Monsoons Panel; furthermore, GEWEX (Global Water and Energy Exchanges) activities in land-atmosphere interaction and convective scale processes are crucial to understanding monsoons at fine and global scales. As a result, a single Monsoons Panel spanning CLIVAR and GEWEX domains was established in 2015, with membership drawn from both the communities; the Panel reports to both CLIVAR and GEWEX Scientific Steering Groups.

Working Structure of the Panel

The Monsoons Panel is supported by working groups in leading regionally focused monsoon research in each of the three distinct monsoon regions of the globe (Figure 3). The Panel defined concrete activities to be fostered in the coming years, coordinating the regional working groups and acting as a hub to facilitate meetings and linkages among international research efforts. Advancing understanding of monsoon variability and improving prediction remain the principal goals promoted by the Monsoons Panel as per WCRP's focus. Observation and modelling are still the cornerstones of the research efforts. The Panel seeks to bring new methods and fresh perspectives to the problem that can enhance monitoring, advance diagnostic steps, and improve component and coupled models. Thus, the key to these efforts will be the development of new and better process studies (particularly emphasizing the role of convection and land-surface processes in monsoon models), coordinating with relevant modelling efforts, including those related to climate change, and empowering the next generation of young scientists from around the world to advance our knowledge of monsoon systems. Scientific works include observational field campaign and process modelling work, coordination of and contribution to climate change efforts in CMIP6, and utilizing our understanding of subseasonal-to-seasonal variability to aid the enhancement of monsoon prediction on these scales.

The three regional monsoons working groups are working towards enhancing understanding of the monsoons in those regions through various process studies with an emphasis on improving prediction skills in those respective areas. The primary focus of these groups is to build a partnership between operational met departments and researchers to sensitize the operational met departments on various strengths and limitations of the present climate models in predicting weather and climate in those regions. The regional working groups also establish sub-groups to focus on different topics. In these sub-groups, researchers beyond working groups, particularly Early Career Scientists (ECS), will be engaged in various process studies to address the significant focus of the regional working groups. The Monsoon Panel guides the working groups on finalizing the multiple elements for research focus, promotes cross-cutting activities across working groups, and synergizes the knowledge generated from these working groups.

The Monsoons Panel actively collaborates with several other groups both within WCRP and outside, with shared interests in different aspects of monsoon research. These include, but are not limited to, the oceanic regional panels of CLIVAR, GEWEX Hydro climatology Panel, and Working Group on Tropical Meteorology Research (WGTMR) of the WMO World Weather Research Programme (WWRP), *etc.* The Monsoons Panel led special issues of CLIVAR Exchanges on India's Monsoon Mission (CLIVAR, 2020) and GEWEX Quarterly on Monsoons of the World (GEWEX, 2020). In collaboration with WGTMR, the Monsoons Panel has provided strong support to the recently held Seventh International Workshop on Monsoons (IWM-7; https://mausam.imd.gov.in/IWM7/) including a training workshop on subseasonal to seasonal prediction of the monsoons. Recently the Monsoons Panel engaged in interactions with SPARC on the role of atmospheric composition in processes relevant for the monsoon , including the Atmospheric Composition and Asian Monsoon (ACAM) activity of SPARC (https://www.sparc-climate.org/activities/asian-monsoon/). The Monsoons Panel is also closely engaged with the ongoing transition to the new implementation plan of WCRP, including the new core projects and Light House Activities, particularly with a focus on regional aspects.

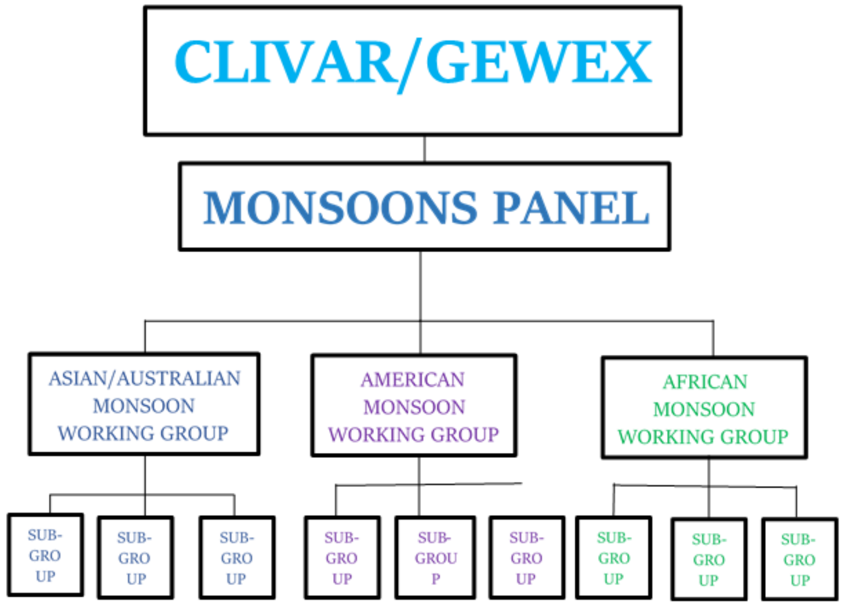

Figure 4: *Working structure of Monsoons Panel.*

The Monsoons Panel is supported by the International Monsoons Project Office (IMPO), hosted by the Indian Institute of Tropical Meteorology (IITM) in Pune, India. IMPO was established through a formal agreement between the World Meteorological Organization (WMO) and IITM, with strong support from the Government of India. For more information on the Monsoons Panel, its regional working groups and IMPO, please visit https://impo.tropmet.res.in/.

Present activities

The current focus of the Monsoons Panel is to identify the bottlenecks to achieve further improved skills in representing the monsoons in dynamical models for weather and climate scales and extremes. The activities lined up for addressing this focused activity include:

- Skill assessment of monsoon rainfall in different regional monsoons and identify the bottlenecks in the dynamical models for further improvement of skill.
- Understanding of dynamical and physical processes associated with extreme events and identifying the lacuna in capturing these extremes in present-day models.
- Research to Operations (R2O) activities to help the Regional Climate Outlook Forums (RCOFs) and operational meteorological services.
- Capacity building through working groups by promoting ECS representation in the working groups and subgroups linked to these working groups.

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Tropical Ozone Trends (1998-2019) from SHADOZ Sondes: A Definitive Reference for LOTUS Analyses

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Hundreds of SPARC scientists have used ozone and temperature data from the Southern Hemisphere Additional Ozonesondes (SHADOZ) network but may not know that SHADOZ is in its 25th year. Initiated in 1998 as a partnership among NASA, NOAA, and partners in 15 nations (Thompson *et al.*, 2003), SHADOZ has archived more than 9200 ozone and pressure-temperature-humidity (PTU) profile pairs collected throughout the tropics and subtropics. The ozone data are obtained from electrochemical concentration cell (ECC) sondes flown with standard radiosondes on a balloon.

SHADOZ network accomplishments at 25 years

With 14 long-term stations in the network (Figure 5), SHADOZ has transformed our knowledge of the tropics in several areas of importance to the SPARC community:

1. Through launches coordinated for satellite validation, SHADOZ has supported more than 20 spaceborne instruments flown since 1998 (Thompson *et al.*, 2019a). The ozone profiles have become indispensable to the development of algorithms for new satellite ozone products. They have also been used to detect and quantify drifts in datasets obtained from satellites.

2. SHADOZ has built capacity in host nations by promoting "twinning" sponsorships that empower operators and data providers through training and participation in instrument tests (Thompson *et al.*, 2019b). This model follows WMO/GAW recommendations that promote an inclusive strategy for developing "best practices" for the preparation of the sonde instrument and data processing. Dozens of data providers and operators learn from each other about how evolving instruments and recommended operating procedures perform in both lab and field.

3. Open access to SHADOZ data at the website, https://tropo.gsfc.nasa.gov/shadoz, with additional archiving at WMO/GAW

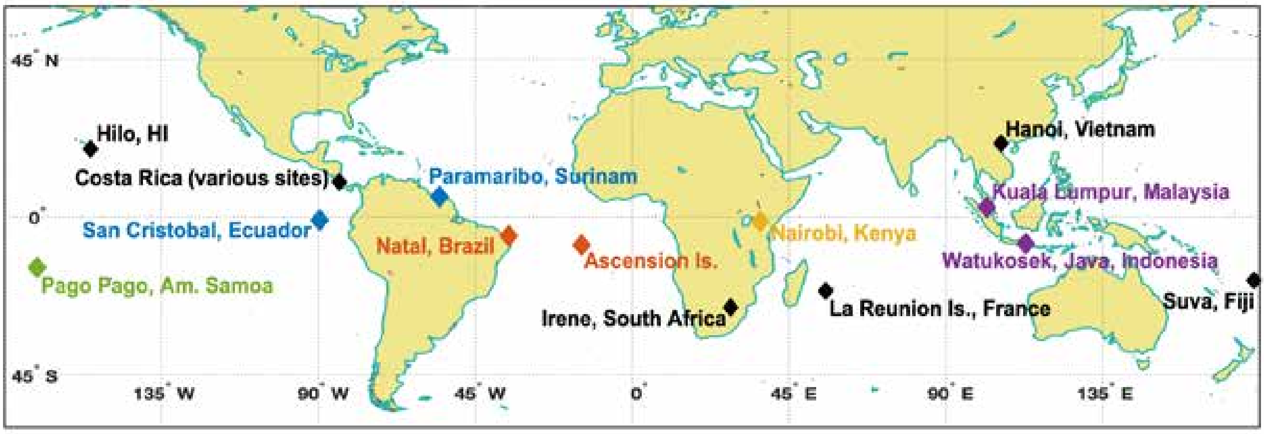

***Figure 5:** Map of 14 SHADOZ stations with at least 10 years of ozone and pressure-temperature-humidity (PTU) profiles at the SHADOZ archive. Stations for which data are used in this study are shown as colored diamonds. "Stations" for which combined records are analyzed are colored blue (San Cristóbal and Paramaribo, referred to as SC-Para), red (Natal and Ascension, Nat-Asc pair), and purple (Kuala Lumpur and Watukosek, KL-Java). Samoa (light green) and Nairobi (orange) records are analyzed with the MLR model individually. The total number of profiles per site used here are listed in Table 2.*

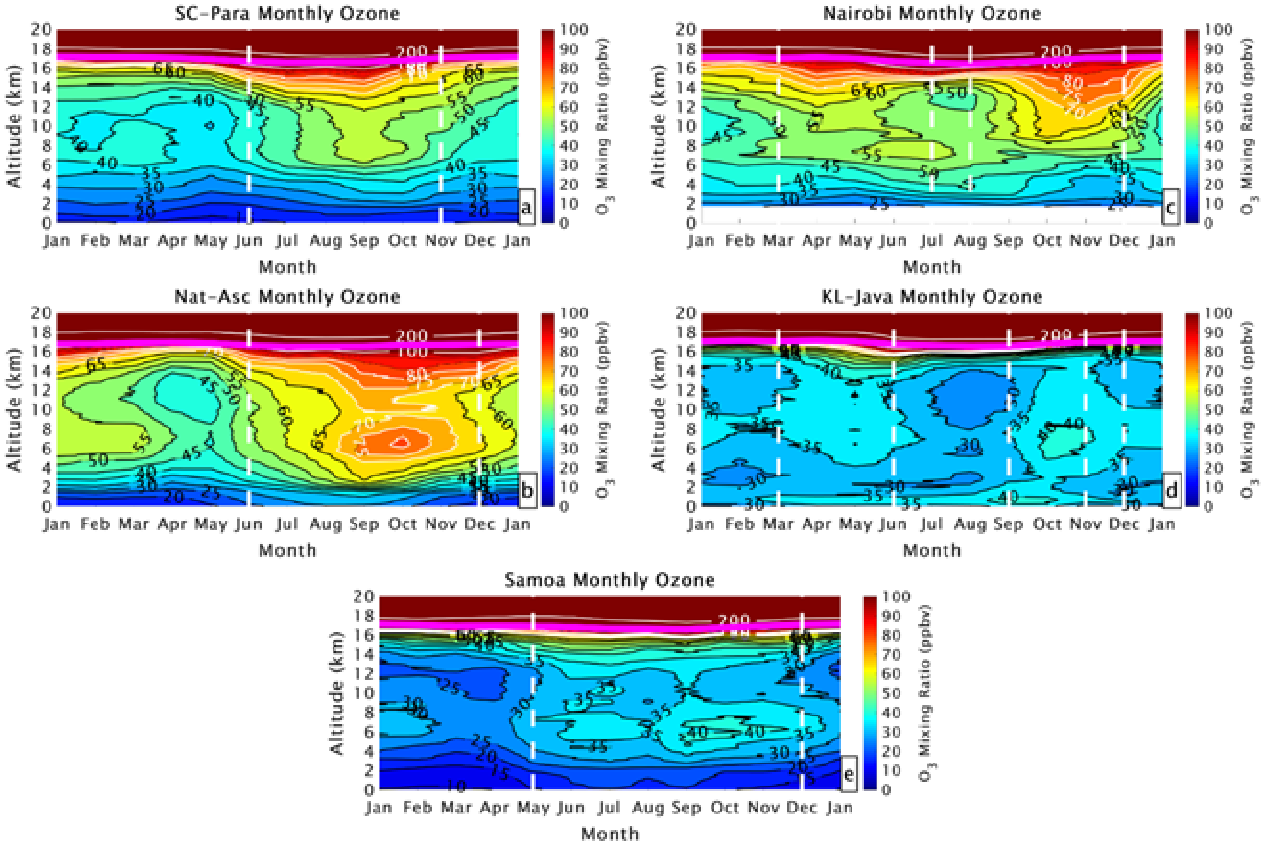

***Figure 6:** Monthly averaged ozone mixing ratios from the surface to 20 km altitude for the five sites. Both white and black contours are shown for the ozone mixing ratios for clarity. The cycle of tropopause height (TH) in altitude derived from the 380 K level of the radiosondes accompanying the ozonesondes is given by the magenta curve. White dashed lines indicate transitions marked by changes in sign of ozone anomalies from annual mean (Figure 4 in T21). The extent of convective influence changes markedly at those transitions (see Figure 5 in T21).*

(woudc.org) has enabled hundreds of scientists to use the profiles.

4. SHADOZ profiles have become a staple in studies of tropical ozone in the stratosphere, the troposphere, and the tropopause transition layer (TTL) between the two. Examples include characterizations of the Quasi-Biennial Oscillation (QBO) and El Niño Southern Oscillation (ENSO), attribution of the wave-one ozone structure in total ozone to tropospheric variability, and the role of convection in intra- and interannual ozone variability in the free troposphere.

Ozonesondes: high-resolution profiles for trends studies

One of the most important contributions of SHADOZ to the SPARC community has been ensuring high quality in the ozone measurement. Since 2004, working in the WMO/GAW framework (Smit *et al.*, 2014; Smit *et al.*, 2021), SHADOZ has been part of the ASOPOS (Assessment of Standard Operating Procedures (SOP) for Ozonesondes) group of experts charged with developing "best practices" for ozonesondes based on multiple-instrument field tests and the Jülich Ozone-Sonde Intercomparison Experiments (JOSIE) series of laboratory comparisons. Twenty years ago, ozonesonde profile and total column ozone (TCO) were assigned a 15-20% uncertainty. With recommendations from ASOPOS, more uniform operational practices have been adopted across the global network. In addition, the ASOPOS Data Quality Assurance for O3sondes (DQA-O3S) group promulgated guidelines for re-processing sonde time-series to minimize discontinuities caused by instrument changes, variations in operator practices and/or data record preparation. The entire SHADOZ dataset covering the period from 1998 through to 2016 was reprocessed in 2017 and 2018 as described in Witte *et al.* (2017). This was around the same time as the ozonesonde records from Canada, Europe, and the NOAA Global Monitoring Laboratory network were reprocessed. Taken together, these stations represent more than half of the global

Station	Latitude/ Longitude	No. Profiles	MLR Terms for Best Fit	LMS, 10-15 km change (%/dec)	Upper FT, 10-15 km change (%/dec)	LMS, TH+5 km change (%/dec)
SC-Para	*5.8,-55/-0.92,-90*	*1227*	*MEI + QBO*	**-3.1**	*+1.5*	*+0.6*
Nat-Asc	*-5.4,-35/-7.8,-14*	*1436*	*MEI + QBO*	*-0.4*	**+3.9**	*+1.9*
Nairobi	*-1.3, 37*	*941*	*MEI + QBO*	*+0.6*	*-0.2*	*+1.9*
KL-Java	*2.7,101/-7.5,113*	*786*	*MEI + QBO +IOD*	**-5.8**	*-0.6*	*-0.5*
Samoa	*14, -171*	*795*	*MEI + QBO*	*-2.8*	*+2.5*	*-0.9*

Table 2: *SHADOZ site metadata including number of profiles and index terms used in MLR ozone calculations, with the MEI used for ENSO. Monthly MLR partial column ozone linear trends over the period 1998-2019 are shown, with significant trends in bold.*

ozonesonde network; the improvements have led to ozone records with a 5-10% uncertainty (Stauffer *et al*, 2020; Tarasick *et al*, 2021). An accuracy of 5% of TCO measurements at all SHADOZ stations was accomplished by reprocessing the SHADOZ data (TCO data at 12 stations have an accuracy of ±2%; Thompson *et al.*, 2017).

Having the newly reprocessed SHADOZ ozone profiles inspired an investigation of ozone trends in the free troposphere (FT) and lower stratosphere after 1998. Motivated by the LOTUS Report (SPARC, 2019) and a series of papers using merged satellite data that suggested losses post-1998 in lower stratospheric ozone, starting with Ball *et al.* (2018), we noted several advantages of the sounding data. First, trends throughout the lower stratosphere, TTL and FT, where ozone is a strong radiative forcer, could be calculated with a single set of profiles. Although sampling in the deep tropics (absolute latitude <15°) is limited to fewer than 10 locations, the SHADOZ record is well-distributed zonally. In this way regional variability in trends can be assessed, in contrast to studies that use zonally averaged merged satellite data. Furthermore, measurements of ozone by ECC sondes are unaffected by clouds unlike many satellite sensors.

Here we summarize highlights of our tropical ozone trends study, published in October 2021 (Thompson *et al*, 2021; hereafter referred to as T21). We used 22 years of reprocessed SHADOZ data (1998-2019; https://doi.org/10.57721/SHADOZ-V06) to (1) update a FT and lowermost stratospheric (LMS) ozone climatology; (2) determine trends in those two regions of the atmosphere; and (3) discuss dynamical characteristics inferred from the SHADOZ radiosonde data that may be related to strong seasonal signatures in both FT and LMS trends.

SHADOZ ozone climatology and trends analysis

To focus on the "deep tropics", data are analyzed from eight SHADOZ stations located within 15° of either side of the equator. Because there have been data gaps at a number of stations, we combine three pairs of stations to have robust statistics for the trend calculation. The pair representing the equatorial Americas, with similar seasonal patterns, combines profiles from San Cristóbal (Galápagos, Ecuador) and Paramaribo (Surinam); referred to as SC-Para. Natal and Ascension are combined for the Atlantic (Nat-Asc), and Kuala Lumpur and Watukosek, KL-Java, are combined,

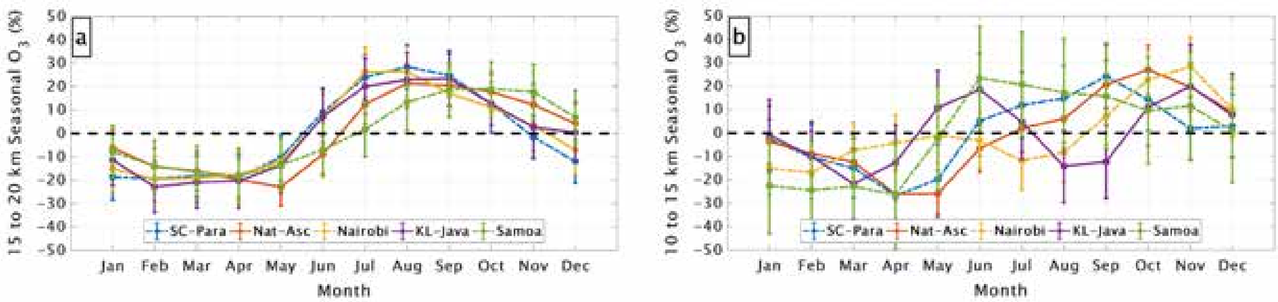

Figure 7: *Monthly mean ozone variability, expressed as percent anomaly from annual mean, from the MLR model in the LMS, defined as the segment from 15 to 20 km (a) and upper FT, defined as 10-15 km (b).*

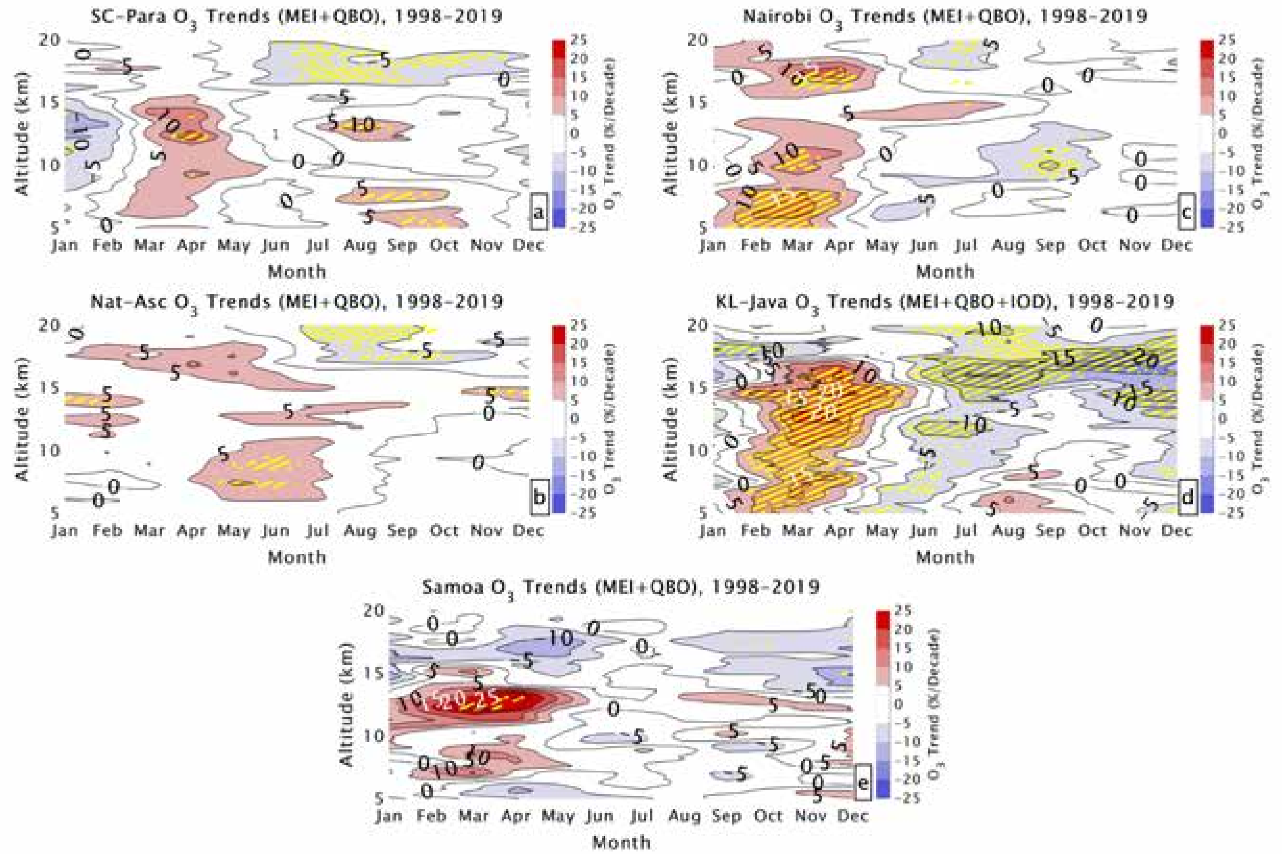

Figure 8: *Monthly MLR ozone linear trends from 5 to 20 km in percent per decade for the two individual and three combination sites. Positive trends are shown in red and negative trends are shown in blue. Trends at the 95% confidence level are shown with yellow hatching.*

representing southeast Asia and the eastern Indian Ocean. In addition to the three combination sites, profiles from Nairobi (equatorial Africa) and Samoa (western Pacific) are analyzed. A summary of the stations, their locations, and profile numbers appears in Table 2.

The seasonality of ozone in the FT, taken here as 5 to 15 km, and the LMS (taken as 15-20 km) is pronounced. This is seen in Figure 6 that depicts contours of mixing ratio (in ppbv) based on monthly means over the period 1998-2019. The lowest ozone amounts in these layers occur from December through February (DJF); this is readily seen in the anomalies computed relative to the annual mean (Figure 7). In the FT, DJF are the months of most intense convection. This is exhibited as more low-ozone air (30 ppbv or less) being transported into the upper troposphere (Figure 6). After July, FT ozone increases, at most locations maximizing in September and October during the southern hemisphere biomass burning season. Ozone pollution from fires can be local, e.g., above 8 km over Natal, Brazil. However, for the most part the enhanced ozone is advected from fire-active regions upwind. For example, the maximum ozone in the middle troposphere over both Natal and Ascension originates from southern African burning that peaks in August to October. Over Kuala Lumpur, elevated ozone is caused by fire pollution from northern Thailand and Laos (March-April); ozone pollution from Africa affects profiles from Watukosek in October.

Trends are determined using monthly mean ozone mixing ratios at 100-m resolution with the NASA/Goddard Multiple Linear Regression (MLR) model (Stolarski *et al.*, 1991). The model is run with v06 SHADOZ data for the period 1998-2019 and includes standard terms for annual, semi-annual cycles and the oscillations typically included for the tropics: QBO, MEI (Multivariate ENSO Index, v2); IOD DMI (Indian Ocean Dipole Moment Index) for KL-Java. Comparison of the MLR model fit to the monthly means shows a correlation of r = 0.83-0.90 for the LMS and 0.66-0.85 for the upper FT (Supporting Information in T21). In addition to running the model on ozone mixing ratios, the MLR was applied to the monthly mean partial column ozone amounts from 5-10 km, 10-15 km, and 15-20 km. Table 2 summarizes trends (in % change/decade) as computed for the partial ozone columns (in Dobson Units, DU; 1 DU = 2.69×10^{16} cm^{-2}) for the LMS taken as 15-20 km; in the 10-15 km segment for the upper FT.

Seasonal and regional variability of FT and LMS ozone trends

Both regional and seasonal variability are prominent in Table 2 and in Figure 8 and Figure 9, where trends are displayed graphically. In the LMS, Table 1 shows that there are four regions where the annual trend is negative, SC-Para and KL-Java being statistically the most significant. There is also a loss of ozone in the LMS over the western Pacific (Samoa) and the Nat-Asc combination, representing eastern South America to the central Atlantic. Only Nairobi of our stations has a small positive trend, +0.6%/decade. Thus, most of the equatorial zone has a slightly thinning ozone layer in the LMS, albeit over a large range: from -0.4%/decade to -5.8%/decade over KL-Java. In Figure 8 it is seen that the LMS ozone loss exhibits a strong seasonal component, with losses occurring only after May, except at Samoa. The loss feature affects only 2-4 months and spans only a few km altitudes over Nat-Asc and Nairobi (Figure 8b and c). The LMS ozone decline over the 22 years is strongest over KL-Java (Figure 8d) in intensity (up to -20%/decade in November and December), extent (13-20 km in December) and in duration (June to February).

Trends in the upper FT, 10-15 km, also vary greatly by region (annual means in Table 2) and season. The most statistically significant increase is over the Atlantic (Atlantic (+3.9%/decade), based on January to June ozone increases, Figure 8b). To the west of this region, over SC-Para, the annual rate of increase is smaller (+1.5%/decade increase, Figure 8a) with a similar seasonal pattern to that over Nat-Asc. The increases in upper FT, layers for these regions range from +5-to-10%/decade and are found from March through June, which is less in magnitude than over Nairobi and KL-Java (Figure 8c and d). In the latter locations January through April, ozone increases range from 10-20%. However, over Nairobi and KL-Java, the larger increases are offset by ozone losses, (5-10)%/decade at 10-15 km between June and September. Thus, the net annual upper FT trends for Nairobi and KL-Java are -0.2%/decade and -0.6%/decade, respectively.

A summary of the seasonality in trends for the LMS and upper FT is given in Figure 9a and Figure 9b, respectively, where percent/decade ozone column changes are shown by month. Both LMS and upper FT ozone increases are greatest between January and April. In the LMS this is markedly so for SC-Para, Nat-Asc, and Nairobi. In the upper FT ozone increases at all five sites during the same months. In a similar way, all stations except Samoa (not shown) have LMS ozone losses concentrated between June and September (Figure 9a). Figure 7a shows that the LMS ozone increase takes place at the annual minimum (February to May) whereas the LMS ozone

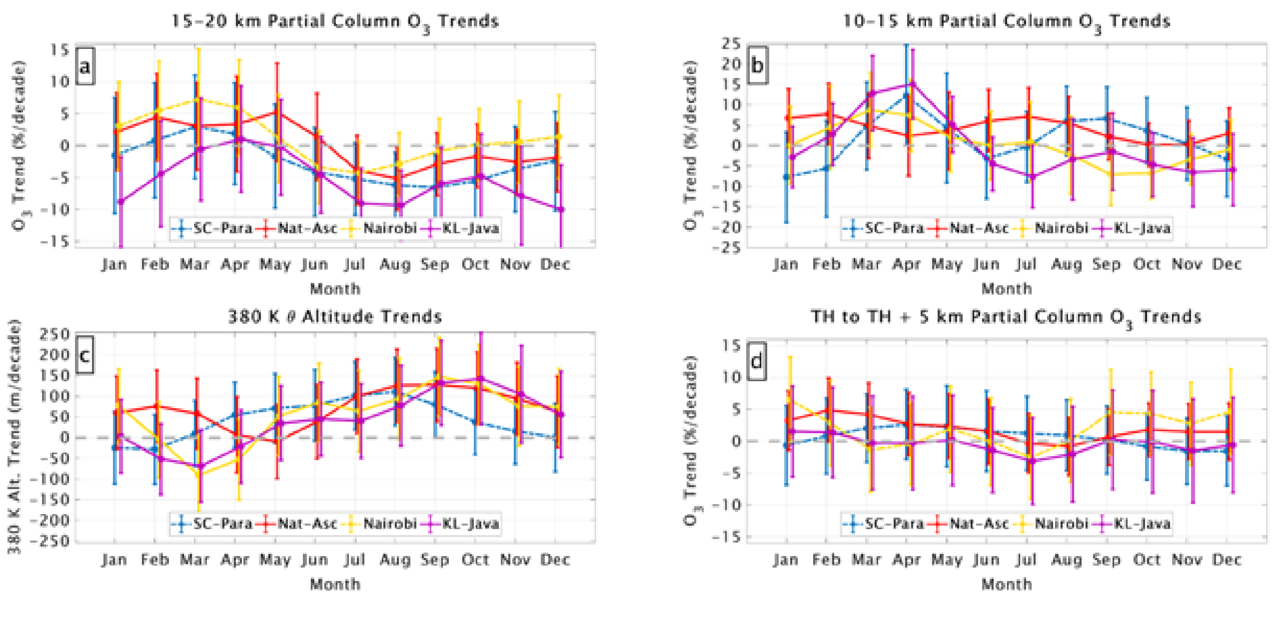

Figure 9: *Monthly MLR trends in %/decade for (a) LMS ozone column, integrated from 15-20 km, and (b) upper FT ozone column (10-15 km), derived from SHADOZ sondes launched in 1998 through the end of 2019. (c) The corresponding trend in TH (in m/decade); (d) LMS ozone column trend with the column defined within the 5 km above the tropopause over 1998-2019. Dots represent the values, and the error bars indicate the 95% confidence intervals.*

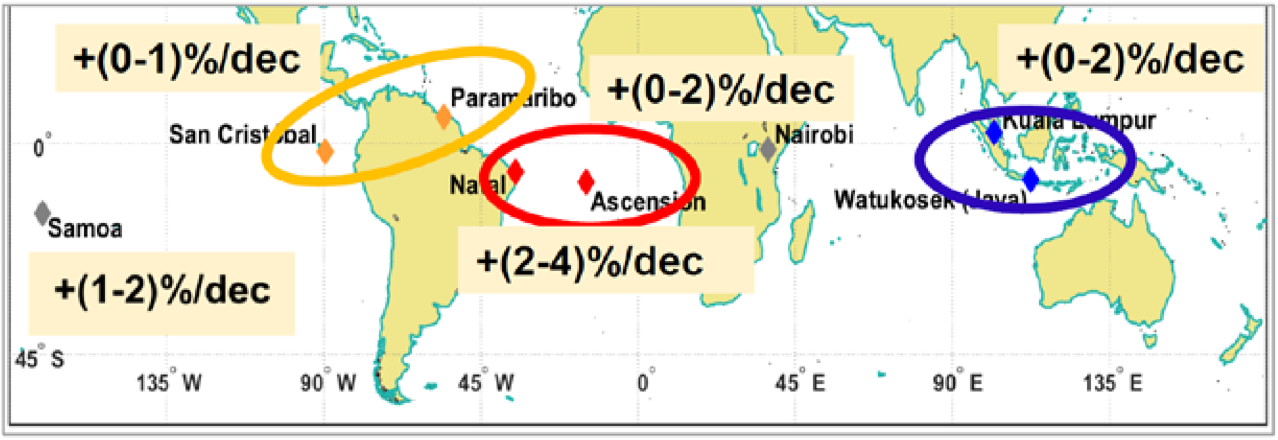

Figure 10: *A summary of ozone trends (% change/decade) in FT with the FT being defined by between 5-10 km and 10-15 km (Table 1 in T21). Note pronounced regional variability with no trends at some stations.*

losses coincide with the annual LMS ozone maximum, July to September. The annual ozone LMS variation, similar at all five stations, is a signature of the annual Brewer-Dobson circulation. The net effect of the LMS ozone trends (Figure 9a) is a flattening of the annual ozone cycle over the period 1998-2019.

The dominant seasonality in upper FT ozone is the increase in the beginning of the year (Figure 8 and Figure 9b); trends become more variable after that. Figure 7b shows that the FT ozone cycle is a minimum in the first part of the year, most notably between March and May (somewhat less so for KL-Java, that is affected by an early-year biomass burning season). The coincidence of increasing upper FT ozone during the seasonal minimum means that the annual ozone minimum is increased. The latter behavior, a positive shift in FT tropical ozone minima has been observed in aircraft (In-service Aircraft for a Global Observing System, IAGOS) data as well (Gaudel *et al.*, 2020).

Interpretation of ozone changes (1998-2019) - tropopause trends derived from SHADOZ data

What are likely interpretations of the observed ozone changes? In both upper FT and LMS there is a dominant seasonality to the trends: increasing upper FT ozone in the first half of the year and LMS ozone losses in the second half of the year, most concentrated during the period July to September. In both layers of the atmosphere, particularly over remote SHADOZ stations far from pollution sources, dynamical influences are likely to play a role.

Because the LMS definition used here is the layer between 15 and 20 km, it is reasonable to ask if there are simultaneous changes in the tropopause height (TH) during the 1998-2019 period (magenta lines in Figure 6). The MLR model was applied to monthly averaged TH, taken as the altitude of the 380K potential temperature derived from the SHADOZ radiosonde data. Significant positive trends are found for tropopause height (Figure 9c) at all stations except Samoa (not shown). Increases of greater than 50 m/decade are found between July and November. For Nat-Asc, Nairobi, and KL-Java the increases exceed 100 m/decade in September and October. Thus, the months of greatest LMS ozone loss are about the same as the most positive trends in TH. What happens when the ozone trends are recomputed in tropopause-referenced coordinates? Annually averaged ozone trends with an LMS defined as the segment between the tropopause to 5 km above the TH are included in Table 2, last column. Graphically, the monthly mean trends in LMS ozone seen in Figure 9a nearly disappear for all stations (Figure 7d) except Nairobi in January. There is a slight increase in the already positive LMS trend between January and May over Nat-Asc, giving an annually averaged 1.9%/decade change (Table 2). Over Nairobi a small annual positive trend (+0.6%/decade) with LMS defined at 15-20 km, grows to 1.9%/decade with the TH-referenced LMS due to increases between September and January.

When trying to understand the changes in FT ozone (Figure 10), it is noted that the early part of the year is a season of dominant convective influence, *i.e.* the southern hemisphere wet season (except for Kuala Lumpur for which convective influence maximizes during the south Asian Monsoon, after July). We have used a combination of thin laminae in both the ozonesonde and

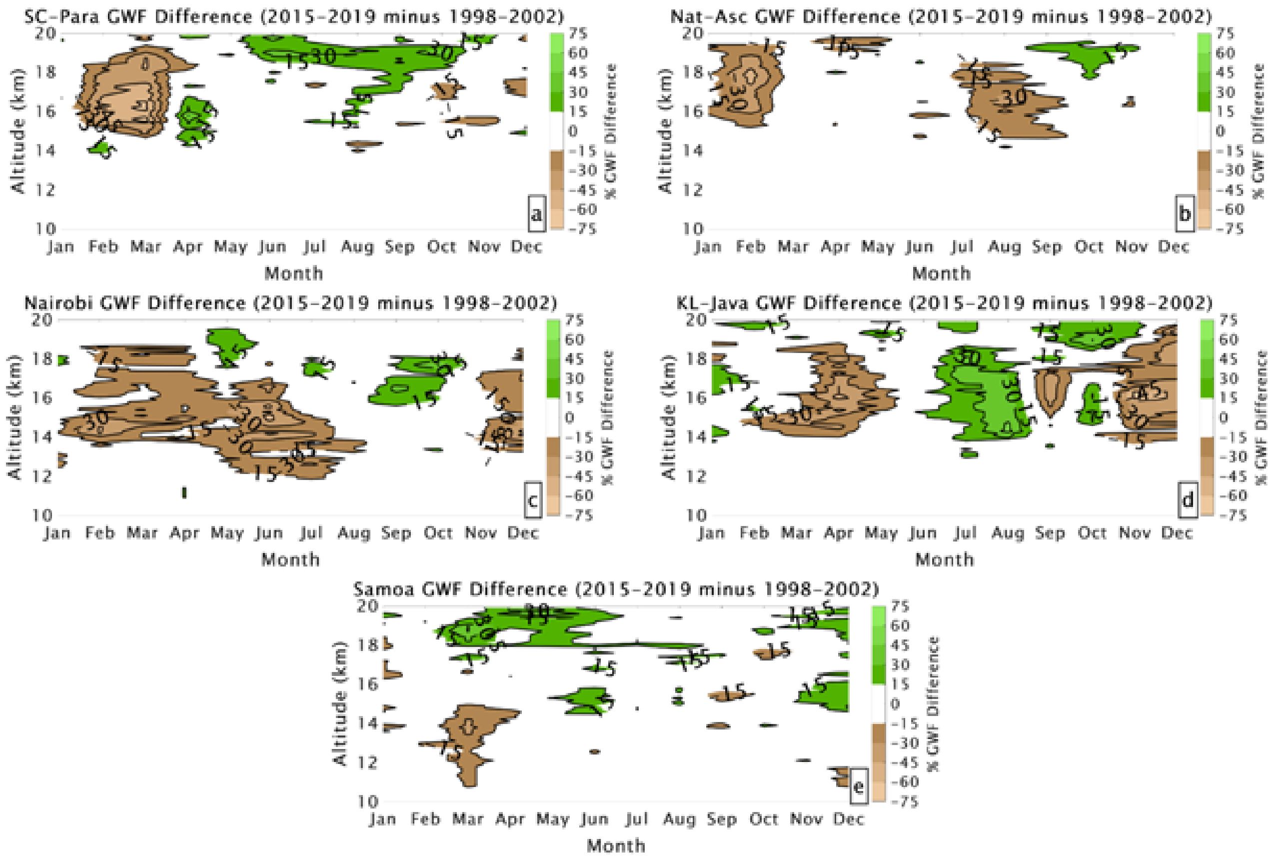

__Figure 11:__ Change in monthly GWF, a proxy for deep convective influence in the tropics, over two periods (2015-2019 minus 1998-2002) from 10 to 20 km altitude. Increases in GWF are shown in green and decreases in GWF are shown in brown for all sites.

accompanying radiosonde (potential temperature) data to infer convectively driven gravity waves (GW) in the FT and LMS for each profile pair. Monthly mean convective influence presented as GW frequency (GWF, Figure 9 in T21) shows that, depending on the station, the percentage of profiles taken during convection in the months February to April, ranges from 50-70%. There is evidence for a decline in convection using GWF in the early part of the year at all five stations (% relative decline in brown; Figure 11) when comparing the mean GWF between the first (1998-2002) and last (2015-2019) years of our record. This suggests a potential qualitative link between increasing FT ozone amounts and decreasing convection, an observation that requires analysis with other proxies for convection, *e.g.*, outgoing long-wave radiation (OLR).

Summary

SHADOZ ozonesonde and radiosonde data, as monthly means from five stations over 22 years (1998-2019), have been analyzed for trends in the FT and LMS. The main results can be summarized as follows:

1. Both the FT and LMS ozone changes over the study period display strong regional and seasonal variability.

2. In the upper FT, ozone has increased at all five sites in the early part of the year although the annually averaged trends range from -0.6%/decade (KL-Java) to +3.9%/decade over the Atlantic.

3. A seasonal upper FT ozone increase, February through May, coincides with the annual ozone minimum and the timing of maximum deep convection at four of the five stations.

4. In the LMS, ozone losses occur at four of five stations during the second half of the year.

5. The greatest LMS ozone losses, (5-10)%/decade, take place from July through September, coincident with a 50-100 m/decade increase in tropopause height (TH) as determined from the SHADOZ radiosonde data.

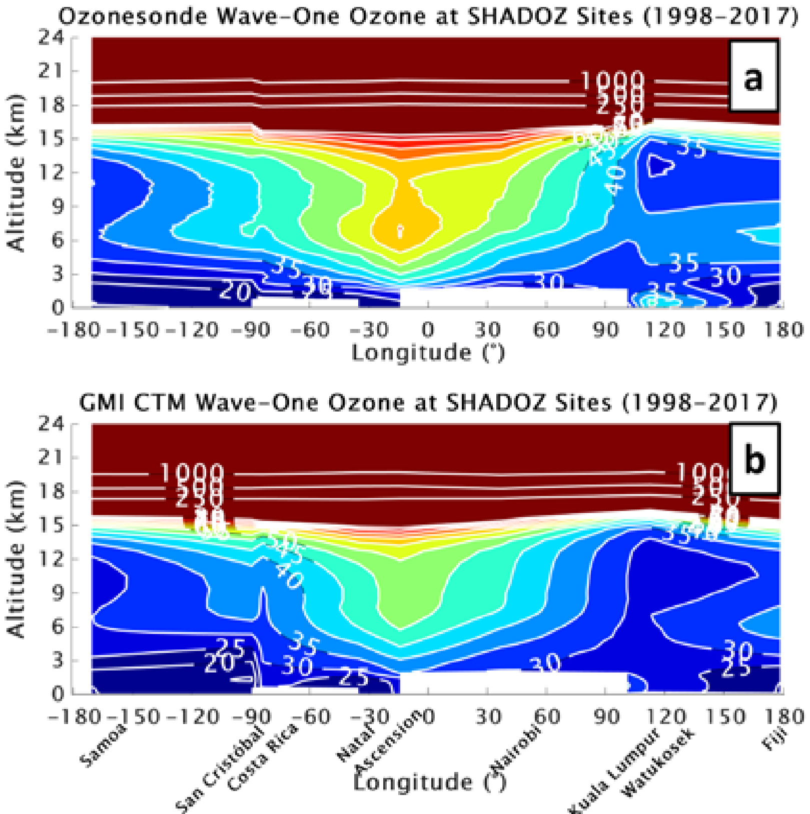

Figure 12: *A zonal cross-section of annually averaged ozone mixing ratio from equatorial SHADOZ stations. The integrated tropospheric (and total) ozone columns display a zonal wave-one pattern due to the greater amount of ozone over the Atlantic than the Pacific. (a) The SHADOZ observations. The upper FT and TTL values from the model fall short of the measurements by 20-40%; (b) Model simulation with the Modeling Initiative (GMI) chemistry transport model CTM (Stauffer et al,. 2019).*

6. When LMS ozone trends are recomputed with column segments referenced to the TH, the losses largely disappear and are positive (~2%/decade) at the Nat-Asc (Atlantic) and Nairobi stations.

SHADOZ data availability for LOTUS, SPARC activities and related trends research

The LMS ozone trends determined from SHADOZ are highly relevant to LOTUS and related communities that compare merged satellite datasets and model output. For example, the finding that LMS ozone losses may be an artifact of TH changes is evidence that dynamical perturbations, neither seasonally nor regionally uniform, are responsible for a two-decade LMS ozone decline inferred from satellite observations (Ball *et al.* 2018), i.e, chemical reactions do not seem to play a role.

We encourage the use of our monthly SHADOZ-derived ozone data and derived trends from model output (available at https://tropo.gsfc.nasa.gov/shadoz/SHADOZ_PubsList.html) as references for evaluating satellite-based ozone datasets and for climate model comparisons. Among important questions that should be addressed are:

- Do zonal mean trends (e.g., LOTUS, 2019) mask regional and seasonal variations in trends that indicate important mechanistic information?

- How well do models simulate ozone in the tropics? Figure 12, for example, compares the output of a typical model (panel) to the zonal ozone structure from SHADOZ data. In the TTL the model ozone by 20-40% (Stauffer *et al.*, 2019).

- Do tropical TH increases over the period 1998 to 2019 appear in re-analyses?

- Is the 1998-2019 TH increase observed in SHADOZ data a signal of changing climate?

Adopting SHADOZ data and trends as the "gold standard" for evaluating satellite products and models in the tropics has advantages that cannot be overstated:

- The data are based on highly accurate, high-resolution (100-150 m) profiles with hundreds of in-situ samples at each location.

- In the tropics the zonal distribution of SHADOZ data captures the full range of dynamic environments: equatorial Americas and Africa, the Atlantic, western and eastern Indian Oceans, western and eastern Pacific, and the south Pacific convergence zone.

- Direct measurement of meteorological conditions from the accompanying radiosondes provides essential dynamical information, e.g. TH, convection, wave activity, for each ozonesonde profile.

We look forward to active collaboration with LOTUS, other SPARC activities, and the larger SPARC community. Presentations from the SHADOZ authors were given to the NOAA Global Monitoring Annual Conference (23-27 May 2022), Trends and LOTUS side meetings held in Helsinki and virtually (29 May-3 June 2022, see page 29). We anticipate presentations at the SPARC General Assembly in Boulder in October and hope to see some of you there.

Acknowledgments

The SHADOZ project has received ongoing support from NASA's Upper Atmosphere Composition Observations Program (previously Upper Atmosphere Research Program) with special thanks to Drs. K. W. Jucks and J. A. Kaye. Additional resources have been provided from Aura and NASA's JPSS Project. We are also grateful to our partnership with NOAA/GML (B. J. Johnson) and the dozens of operators and other personnel from around the world who have tirelessly collected sonde data for 25 years.

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OCTAV-UTLS activity: update from the March 2022 workshop

Irina Petropavlovskikh[1], Harald Bönisch[2], Michaela Hegglin[3], Peter Hoor[4], Paul Jeffery[5], Daniel Kunkel[4], Thierry Leblanc[6], Gloria Manney[7], Luis Millán[6], Kaley Walker[5], and Hao Ye[8]

[1]CIRES/NOAA, USA, [2]KIT, IMK-ASF, Germany, [3]Forschungszentrum Jülich/Wuppertal University, Germany, [4] Johannes Gutenberg University Mainz, Germany, [5]University of Toronto, Canada, [6]Jet Propulsion Laboratory, California Institute of Technology, USA, [7]NWRA/NMT, USA, [8]University of Reading, UK.

Dates:
29 March - 1 April 2022

Organizing Committee:
Luis Millán,
Peter Hoor and
Irina Petropavlovskikh

Meeting venue:
Online

Number Of Participants: 11

Number Of ECR Participants: 2

Event Website:
https://www.octav-utls.net/

Introduction

The distribution of tracers in the Upper Troposphere and Lower Stratosphere (UTLS) shows large spatial and temporal variability covering a broad range of scales, directly linked to tropopause variations and the dynamical structure of the UTLS. Tropopause and jet variations are strongly linked with the competing transport, chemical, and mixing processes near the tropopause, introducing large variability in composition and observed trends in species with large gradients near the tropopause. This, in turn, strongly affects quantitative estimates of the impact of radiatively active substances, including ozone and water vapor (*e.g.* Forster and Shine, 1997, Riese *et al.*, 2012) on surface temperatures. It also complicates the investigation of dynamical processes, such as stratosphere-troposphere exchange (STE), and their impacts deduced from tracers of transport such as carbon monoxide (CO) or others.

The main goal of the OCTAV-UTLS activity is to characterize observed atmospheric composition variability in the UTLS that is driven by dynamical processes (*e.g.*, upper tropospheric jets and fronts, tropopause folds).

The community is facing the challenge of explaining the UTLS variability and its long-term trends given the limitations of observational datasets, including:

1. Insufficiently fine vertical resolution of global measurements in the UTLS (*i.e.* satellites), which makes the separation of processes and reservoirs difficult.

2. Limited horizontal coverage for measurements with the sufficiently fine vertical resolution (*e.g.*, ozonesondes and aircraft).

3. Partial and potentially biased view of atmospheric processes resulting from the inevitable coupling between the instrument-dependent sampling and the wide range of temporal and spatial scales of atmospheric variability.

Sponsors:

Therefore, it is important to understand the quality and representativeness of all available observations before combining information gathered by different observing platforms (*i.e.* remote sensing from satellite and ground, in-situ measurements from aircraft and balloons) to assess the contribution of dynamical processes to any trends observed.

The first milestone of OCTAV-UTLS collaborations was to develop and apply common metrics as well as the same meteorological dataset to compare UTLS data collected by different platforms. This step was accomplished using the JETPAC (JEt and Tropopause Products for Analysis and Characterization, Manney *et al.* 2011) tool that provides dynamical diagnostics at the measurement locations of each instrument that can be used to map the observations into geophysically-based coordinate systems (*e.g.*, tropopause-relative, equivalent latitude, jet-focused).

Workshop summary

The OCTAV-UTLS workshop was held interactively online over 4 days at the end of March 2022 with alternating online plenary gatherings to discuss specific tasks for ongoing and future data analysis to detect ozone patterns and data variability in UTLS. These were addressed in individual sub-groups to prepare data analyses for the next day's meeting. This led to a very productive and efficient meeting and highly focused work towards a common cross-platform approach as outlined above. The leading experts on the relevant measurements (ozone, water vapor, and other species) from selected platforms, members of the modeling community specializing in model-measurement comparison, and leading experts on JETPAC data analysis attended this workshop to ensure that the data intercomparisons generate the best available information on data quality for future use in model-measurement intercomparisons, instrument development, and trend analysis.

The goal of the 4-day workshop was to interactively progress towards the selection of optimal dynamical coordinates that separate observed ozone records in regimes (regions/times) controlled by individual geophysical processes governing the UTLS trace gas variations. Based on the interactive discussions we identified the most promising coordinate system that will help analyze atmospheric composition spatial and temporal variations as captured by different datasets in a consistent manner. This work will be summarized in a future publication; an outline of

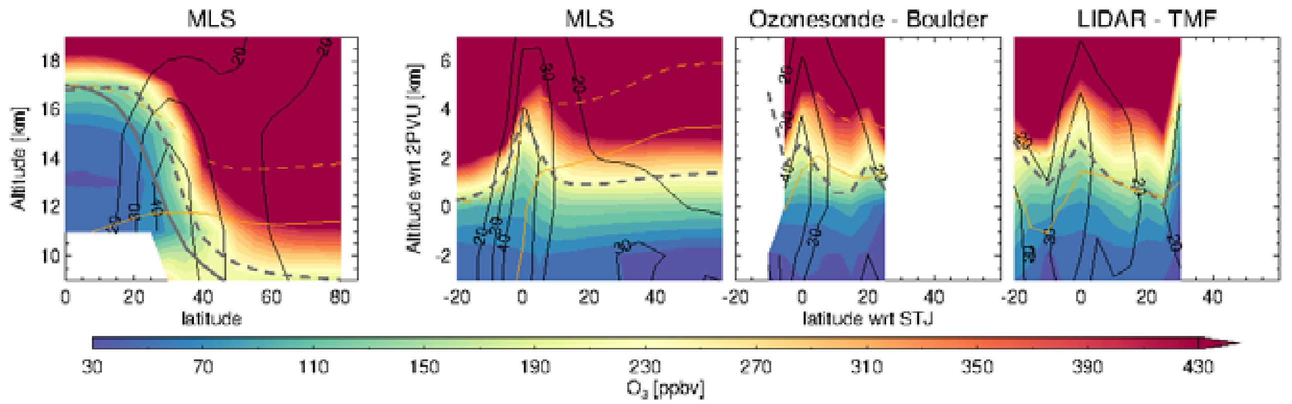

Figure 13: *Ozone data for December-January-February (DJF) 2005-2018 using conventional coordinates (left panel) and dynamical coordinates (right panels) for MLS, ozonesonde in Boulder Colorado, and lidar JPL-TMF in Wrightwood California, with overlaid wind-speeds from MERRA-2, interpolated to the measurement locations (black), 2PVU dynamical and WMO tropopauses (solid and dashed gray lines), and 345K and 380K potential temperature contours (solid and dashed orange lines).*

the paper was discussed and the leads for each section were identified on the last day of the workshop. Figure 13 provides an example of the MLS ozone data (December-January-February, 2005-2018) in conventional coordinates and resampled in a dynamical coordinate system. Also shown are ozonesonde (Boulder) and lidar (JPL-TMF; Table Mountain Facility) records resampled in the same dynamical coordinates system as the MLS record.

Concluding remarks

Based on the analyses of UTLS ozone variability from regular aircraft observations, soundings, lidar, and satellite data (MLS, ACE-FTS) we identified sets of PV-based (equivalent latitude) tropopause relative coordinates and potential temperature to best account for tropopause-induced dynamical variability of ozone for the respective hemisphere. Jet-relative latitude serves as a very helpful coordinate to account for transport processes and mixing in the vicinity of the subtropical jet (typically 30 degrees latitude and extending into the lowermost stratosphere). These results are currently being prepared for publication. Based on this we will proceed to compare trend analyses from the different observational data sets by applying the metrics that have been decided on as mentioned above to detect long-term changes in UTLS composition including ozone, water vapor, and other trace gases. The activity will produce recommendations for data comparisons in the UTLS region based on specific techniques/instruments. We will further provide an assessment of gaps in current geographical/temporal sampling of the UTLS region that limit determining variability and trends and suggest future measurement strategies that would help fill those gaps.

Acknowledgments

Activities under the OCTAV-UTLS are funded by community efforts. IP would like to express gratitude for support from the NOAA Climate Program Office and Global Monitoring Lab of the ESRL, Boulder, Colorado, USA. Part of the work by TL was carried out at the Jet Propulsion Laboratory, California Institute of Technology under a contract with the National Aeronautics and Space Administration (80NM0018D004). KW' and PJ's work at the University of Toronto was supported by a grant from the Canadian Space Agency (16SUASCMEV) and was partially funded by ESA (Contract No. 4000123554) via the Water_Vapour_cci project of ESA's Climate Change Initiative (CCI).

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3rd international workshop on Stratospheric Sulfur and its Role in Climate

Landon Rieger[1], Graham Mann[2], Larry Thomason[3], and Suvarna Fadnavis[4]

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Dates:
16 - 18 May 2022

Organizing Committee:
Graham Mann, Larry Thomason, Suvarna Fadnavis, Landon Rieger

Meeting venue:
University Leeds, UK

Number Of Participants: 90

Event Website:
https://eu.eventscloud.com/ehome/200197691

Sponsors:

Introduction

After the 2-year period of Covid travel restrictions, the 3rd international workshop of the SPARC Stratospheric Sulfur and its Role in Climate (SSiRC) activity was finally able to take place from 16th to 18th May 2022. Hosted at the University of Leeds, U.K., the SSiRC workshop welcomed around 60 in-person attendees for the three-day meeting, as well as 30 participating remotely. The workshop program included 55 oral talks and 16 posters during the conference related to measurements and modeling of stratospheric aerosols, their precursors, climate impacts, and recent volcanic and wildfire events.

Wildfires and Recent Extreme Events

The unprecedented recent intense forest fires in the Pacific Northwest, Canadian Rockies, and Australia have produced volcanic-level enhancements of the stratospheric aerosol layer with atypical composition. This has led to unique radiative properties and chemical interactions and driven numerous studies on the climate and evolution of these unique events. On Monday, **Omar Torres** and **Mahesh Kovilakam** presented satellite observations of these unprecedented fires while **Pengfei Yu, Pasquale Sellitto, Susan Solomon** and **Christoph Brühl** explained their impact on radiative heating, ozone and nitrogen oxides (NOx) chemistry and climate impacts. In addition to extreme fires, the Raikoke eruption injected substantial sulfur dioxide (SO_2) into the stratosphere in 2019, producing marked enhancements to the aerosol optical depth in the Northern Hemisphere. **Michael Fromm**, and **Yaowei Li** presented new information on the circulation, SO_2 injection, and microphysical evolution of the eruption from satellite measurements, models and aircraft campaigns.

Hunga-Tonga eruption

The 15th January 2022 eruption of Hunga-Tonga reached altitudes in the stratosphere never before seen in the satellite era. Combined also with the unique eruption characteristics that injected large amounts of water, the Hunga-Tonga eruption has sparked intense interest on the SSiRC mailing list and community in general. The SSiRC workshop had two blocks dedicated to the eruption with 13 speakers presenting. **Ghassan Taha, Karen Rosenlof, Alexandre Baron, Bernard Legras, Elizabeth Asher, Corinna Kloss** and **Eduardo Landulfo** presented recent measurements of the aerosol plume, with **Sandip Dhomse** showing simulations of the aerosol evolution. **Paul Walter, Hugh Pumphrey, Stephanie Evan, Sergey Khaykin, Yunqian Zhu**, presented work on the unique chemical composition of the eruption, in particular the large amounts of water vapour.

Figure 14: Sunday evening Icebreaker at Thai restaurant.

Figure 15: Monday evening informal dinner at Indian restaurant.

CMIP6 and climate modelling

With the recent publication of the IPCC AR6 report, the climate impacts of volcanic eruptions and stratospheric aerosols are also front-and-center, kicking-off day 2 of the workshop. Invited speaker **Gabi Hegerl** led the session with a talk on climate attribution with **Lauren Marshall, Fei Liu, Sandra Wallis** discussing global and regional responses to large eruption in the climate record. **Anja Schmidt** (presented by Lauren Marshall) discussed the ability of analyzing the climate response in near real time with **Daniel Murphy** presenting the role of particle size on climate forcing calculations. Extending the session into the future, **Daniele Visioni** and **Ewa Bednarz** presented work on the potential climate impacts of stratospheric sulfate aerosol injections.

Volcanic Aerosol Modelling

The evolution and impacts of a volcanic eruption depend crucially on the properties of the initial injection. **Matthias Kohl, Zhihong Zhuo, Ilaria Quaglia, Georgiy Stenchikov** and **Graham Mann** presented work on the modelling of aerosol plumes, including the dependence of the plume evolution on the chemical makeup, as well as the sensitivity to injection latitude and altitude.

Non-sulfate sources and Asian Tropopause Aerosol Layer (ATAL)

While the stratospheric aerosol layer is often considered to only be sulfates, the layer's composition is markedly more diverse. Meteoric particles play an important role in the formation and chemical composition of stratospheric aerosols, and **John Plane, Kamalika Sengupta** (presented by **Graham Mann**), and **Alexander James** presented work on the transport and role of meteoric smoke in aerosol formation. The presence of organics within aerosol in the Upper Troposphere and Lower Stratosphere is another interesting aspect and **Johan Friberg** and **John Dykema** presented work on the role and climate impacts of these organics.

The Asian summer monsoon provides a unique pathway to the upper troposphere and stratosphere that leads to the ATAL. Only recently discovered, the ATAL has been the focus of intense study over the last decade with **Suvarna Fadnavis, Mian Chin**, and **Jie Gao** presenting work on the sources contributing to the ATAL and the climate impact.

Satellite and In-situ Measurements

The size distribution of stratospheric aerosols continues to be a major source of uncertainty, both in understanding remote sensing measurements and climate impacts. **Troy Thornberry, Lars Kalnajs** and **Terry Deshler** discussed recent work on in situ observation of particle size using aircraft and balloons, while **Christine Pohl** and **Felix Wrana** presented retrievals of particle size from limb sounding satellite observations.

Juan Carlos Antuña Marrero summarized work on the SSiRC data rescue activity including recently recovered lidar and searchlight measurements of the Agung aerosol cloud. These themes were continued in the breakout session, aligned to the VolRes activity for response plan for a future major eruption, with talks from **Jean-Paul Vernier, Terry Deshler**, and **Eduardo Landulfo** highlighting recent balloon campaigns measuring the Hunga-Tonga aerosol, a look back at the response after Pinatubo, as well as an overview of the Latin America Lidar Network.

Acknowledgements

SSiRC would like to thank the University of Leeds and the School of Earth and Environment for hosting as well as providing excellent technical and organizational support. In person attendance for many ECRs and scientists from the global South would not have been possible without the travel support provided by SPARC, SSAI and NASA.

Figure 16: *Participants of the 3rd international SSiRC workshop, which was taken prior to the Tuesday workshop dinner.*

Report from the SPARC-LOTUS Workshop in Helsinki

Mark Weber[1], Irina Petropavlovskikh[2], Robert Damadeo[3], Sophie Godin-Beekmann[4], Birgit Hassler[5], Daan Hubert[6], and Viktoria Sofieva[7]

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Dates:
2 - 3 June 2022

Organizing Committee:
Irina Petropavlovskikh, Sophie Godin-Beekmann, Daan Hubert, Viktoria Sofieva, Robert Damadeo and Birgit Hassler

Meeting venue:
FMI, Helsinki, Finland

Number Of Participants: 33 (ECR: 7)
Event Website:
https://trends2020.fmi.fi/program.html

Sponsors:

Introduction

The Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) workshop with two half-day sessions took place as a side meeting to the 11th International Workshop on Long-Term Changes and Trends in the Atmosphere (TRENDS2020) in Helsinki, 30th May 3rd June, 2022. LOTUS is a SPARC activity since 2016 (https://www.sparc-climate.org/activities/ozone-trends/). The first session consisted of several talks while the second day focused on discussing potential new activities and research in preparation for a proposal for the third phase of LOTUS.

Workshop summary

The first session was opened by **Sophie Godin-Beekman**. She gave a brief overview of the LOTUS phase 1 and 2 activities and presented the most recent results on ozone profile trends. The main outcome of the first phase of LOTUS was the so-called LOTUS report (SPARC/IO3C/GAW, 2019), which described in detail trends derived from various merged ozone profile datasets, from which also combined trends and uncertainties were derived. This report provided important input to the 2018 World Meteorological Organization (WMO) ozone assessment (Braesicke and Neu *et al.*, 2018). The profile trends have been updated to the end of 2020 as part of the phase 2 activity. Positive trends attributed to ozone recovery are observed in the upper stratosphere at all latitudes (see Figure 17) confirming prior results. Statistically non-significant trends were observed in the middle and lower stratosphere. Extending the ozone datasets by four years and an improved regression model led to reduced uncertainties in the trend estimates.

Roeland van Malderen reported on the harmonization of long-term ozone sonde data records. To date, data from 43 stations worldwide have been involved in the harmonization efforts. This activity was guided by the O3S-SDQA (Ozone Sonde Data Quality Assessment Activity) since 2011. Corrections to the station data depend on the electrochemical concentration cell (ECC) sonde type, sensing solution, pump efficiency, and total ozone normalization among others. Uncertainties can be thus reduced from 10-20% down to 5% (troposphere/stratosphere) and 10% (tropopause

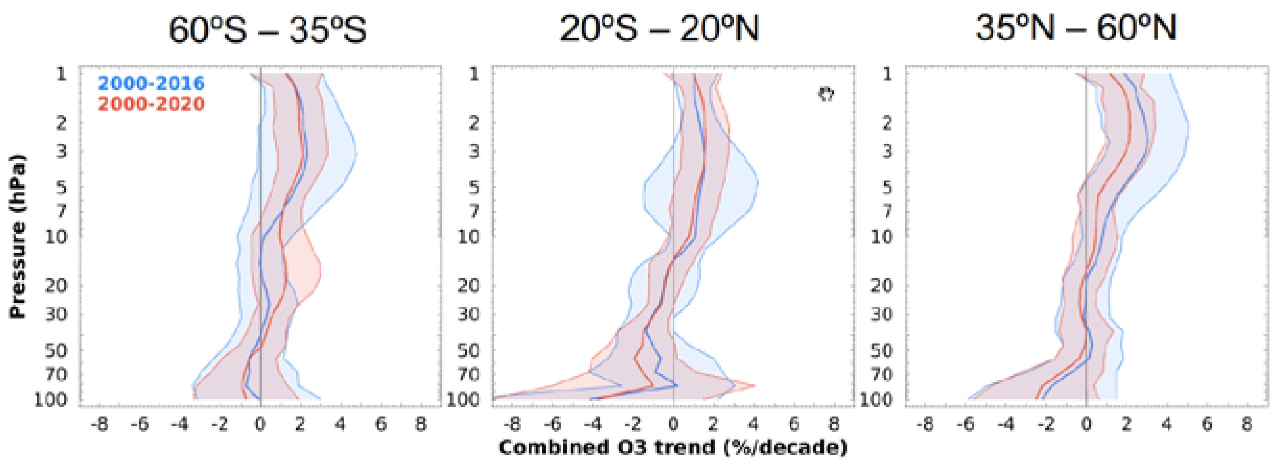

Figure 17: *Combined ozone trends from seven merged satellite datasets during the period up to 2016 (blue) and up to 2020 (red). Uncertainties (shaded area) are given in 2σ. From Godin-Beekmann et al. (2022).*

region). Long-term trends derived from the harmonized sonde datasets are now in better agreement with Lidar (Light Detection and Ranging) and satellite-derived trends. Reprocessing also helped in reducing the drop-off in sonde total columns observed at selected stations after 2013 (Stauffer *et al.*, 2020). Data from 15 additional stations are in the pipeline to be harmonized and added to the database.

Stacey Frith and **Jeannette Wild** gave an overview of the merged SBUV (Solar Backscatter Ultraviolet Radiometer) ozone profile data from NASA and NOAA, respectively. The NASA MOD (Merged Ozone Data) adjusts the various SBUV instruments by improving their spectral calibrations and by accounting for instrumental orbit drifts and diurnal variations before merging. Comparisons of upper stratospheric trends derived from NASA MOD v2 with Aura MLS (Microwave Limb Sounder) show good agreement. The NOAA COH (Cohesive Data) uses overlapping periods to remove biases between instruments. The new v2 of NOAA COH shows better consistency with NASA MOD v2 and Aura MLS than with MOD v1. The use of a tropospheric ozone climatology in MOD V2 is likely responsible for larger biases between the NASA and NOAA merged data at the lowest altitudes, particularly in the tropics.

Results of the S-NPP (Suomi National Polar-orbiting Partnership) OMPS (Ozone Mapping Profile Suite) satellite limb profile (OMPS-LP) comparisons against co-incident homogenized ozone sonde records from the TOAR-II HEGIFTOM (Harmonization and Evaluation of Ground-based Instruments for Free Tropospheric Ozone Measurements) archive were presented by **Yue Jia**. Co-authors found that the OMPS-LP record exhibits a negative trend above 20 km, while MLS v5 tends to show a positive trend. Based on previous studies, the MLS record has no detectable drift. The altitude- and latitude-dependent evaluation of OMPS-LP v2.5 data finds the largest drift (about 5 %/decade) at midlatitudes and 30-40 hPa in the tropics.

Robin Bjorklund reported on long-term ozone profile measurements with different ground-based instruments located at Lauder, New Zealand. NIWA (National Institute of Water and Atmospheric Research) is running the NDACC (Network for the Detection of Atmospheric Composition Change) supersite at Lauder operating an FTIR (Fourier transform infrared) spectrometer, Lidar, a microwave spectrometer, ozone sondes, and a Dobson (Umkehr) spectrophotometer. Detailed comparisons show that the biases between the various instruments are on the order of 4 to 10% after accounting for differences in the vertical resolution of the different instruments and methods.

Increasing surface ozone and tropospheric ozone in Antarctica and possible drivers of the increases since 1992 were presented by **Pankaj Kumar**. The ozone increases were found to be a common feature in different locations across Antarctica. Backward trajectory analyses linked the increasing ozone levels in the lower-middle troposphere across Antarctica to the long-range transport from the nearby continents, where human-driven pollution is rising, and to increasing ozone transport from the stratosphere. More data and modelling efforts are needed to understand the drivers of the increasing surface and tropospheric ozone and evaluate the impact of the increasing surface ozone on both the Antarctic climate and beyond.

An overview of future ozone and UV surface irradiance changes due to increasing greenhouse gases based on chemistry-climate model (CCM) runs, was given by **Kostas Eleftheratos**. The reduction in UV surface radiation will be mainly due to ozone recovery during the first half-century while increasing cloud cover play a stronger role in the second half of this century. The albedo decrease in the polar region will be the dominant contributor to reduced polar UV exposure in the latter half of this century.

Kleareti Tourpali discussed ozone trends and variability derived from CCMI-2020 Ref D1 models (Chemistry-Climate Model Initiative - 2020). The trend results are quite similar to those from the past CCMI Phase-1 Ref C2 model runs and are consistent with observed trends.

As part of the TRENDS2022 workshop, additional talks on updated ozone datasets and ozone trends derived from satellite and ground-based data as well as model data were given (https://trends2020.fmi.fi/program.html). Some of the results from these talks were also summarized in the presentation by Sophie Godin-Beekmann (see above) and found their way as well into the current WMO ozone assessment to be published by the end of 2022.

On the second day, new potential topics and activities for the third phase of LOTUS were discussed. The third phase shall provide important input to the next WMO ozone assessment in four years (2026). Six preliminary themes were identified for Phase 3:

1. Trend analysis techniques (e.g. dynamical linear model, other variants of multiple linear regressions like Lasso, and new proxies and alternative altitude coordinates, e.g. relative to tropopause height),
2. Partial column trends (e.g. consistency between total column and stratospheric/tropospheric column trends),
3. Trends in the UTLS,
4. Improved consistency between satellite and ground-based data,
5. Polar ozone trends,
6. Interconnections between temperature and ozone trends.

Extended discussions were carried out on potential collaboration with other activities, *e.g.* SPARC OCTAV-UTLS (Observed Composition Trends And Variability in the Upper Troposphere and Lower Stratosphere), IGAC TOAR II (Tropospheric Ozone Assessment Report II), and SPARC ATC (Atmospheric Temperature Changes and their Drivers) to broaden the view as part of the new SPARC strategy. **Andrea Steiner** (co-lead of ATC) and **Peter Hoor** (co-lead of OCTAV-UTLS) attended the LOTUS meeting and provided valuable input to this discussion.

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SPARC Gravity Wave Symposium

Riwal Plougonven[1], Laura Holt[2], Corwin Wright[3], Ulrich Achatz[4], Joan Alexander[2], and Kaoru Sato[5]

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Dates:
28 March - 1 April 2022

Organizing Committee:
Ulrich Achatz and Aurelia Müller, M. Joan Alexander, Kaoru Sato, Laura Holt and Riwal Plougonven

Meeting venue:
Goethe Universität Frankfurt am Main

Number Of Participants: 154

Event Website:
https://www.goethe-university-frankfurt.de/87102642/2022_SPARC_Gravity_Wave_Symposium

Sponsors:

Introduction

The SPARC Gravity Wave Symposium was held in Frankfurt from 28 March to 1 April 2022 and was organized by **Ulrich Achatz** and **Aurelia Müller** of the Goethe University of Frankfurt. The meeting brought together 154 participants from 12 countries, in the very pleasant Conference Center of the Evangelische Akademie in the medieval center of the city. The meeting was in hybrid format, and many participants followed the talks online, while two fifths of the talks were given remotely and recordings of the talks were made available. The general sense of relief and thankfulness on site, from participants finally able to benefit of live interactions from one-on-one side discussions to plenary discussions, and the multiple questions and exchanges involving both online and in-person participants, throughout the week and into the final lively discussion which closed the meeting, suggest that the hybrid format was a real success, well worth the difficult and complicated planning and organization.

The title of the meeting was 'Atmospheric gravity waves: towards a next-generation representation in weather and climate models'. Its timing coincides with the ending phase of the MS-GWaves program in Germany, funded by the German Research Foundation (DFG) and coordinated by Ulrich Achatz. MS-GWaves has given a considerable impetus to research on gravity waves, which was illustrated by multiple contributions at the Symposium, ranging from theory to observational campaigns, and from modelling to laboratory experiments. Below we attempt to summarize and illustrate the main highlights from the meeting.

Gravity wave sources

Over the past few years, several campaigns have provided important new insights on the dynamics of atmospheric gravity waves, and on the ability of models to reproduce their essential features. Multiple instrumental techniques were combined during the SouthTRAC campaign (2019) over the Andes and Southern Ocean (**S. Gisinger, N. Kaifler**). Comparison of measurements to different modelling tools, from Numerical Weather Prediction (NWP) to ray-tracing models, confirmed the efficiency of the modelling tools to capture the behaviour and propagation of the excited waves on scales of several tens to hundreds of kilometers. Both observations and models display and confirm significant lateral propagation above the Drake Passage, the imprint of orographic waves in the middle atmosphere covering an area much larger than the orography causing them (**R. Reichert**). Theoretical issues such as the effect of a boundary layer on mountain waves have been revisited by **F. Lott**.

The very recent volcanic eruption of the Hunga Tonga was an unprecedented opportunity to stitch together multiple observations to form a complete view of the concentric waves emitted from an unusually compact source (**C. Wright**). Although anecdotal regarding their impacts, such sporadic sources (including the volcanic eruptions (**J. Yue**) or solar eclipses (**J. Gong**) provide precious tests for evaluating our understanding and our models.

High-resolution simulations have become a major tool for providing information about the atmospheric gravity wave field. Whether conducted as dedicated simulations for case studies (**C. Kruse, C. Meyer**) or in a more general framework for purposes not emphasizing gravity waves (*e.g.* DYAMOND (DYnamics of the Atmospheric general circulation Modeled On Non-hydrostatic Domains) simulations, **C. Stephan**), kilometer-scale simulations provide a realistic description of part of the wave spectrum, and of part of the lifecycle of gravity waves. This allows to explore the partitioning of the wave field into resolved and parameterized parts (**I. Polichtchouk, A. van Niekerk**) and spectral distributions of different motions (**Y.M. Avalos**). Difficulties and challenges emerge from practical aspects (manipulation, analysis and sharing of huge datasets), to more fundamental issues: validation of the gravity wave field, determination of the role of model dissipation and effective resolution, aspect ratio of the grid spacing (**A. Schneidereit**), analysis strategies and methodologies (**J. Wei, N. Zagar**). These high-resolution simulations also allow the investigation of the effect of wave-wave interaction in shaping the simulated spectra (**H. Kafiabad**).

Recent observations from super-pressure balloons have contributed to quantifying the relationship between convective sources and high-frequency gravity waves in the lower stratosphere (**M. Corcos**). At higher latitudes, the contribution of tropopause disturbances as a source has been investigated from campaign observations and model output (**A. Dörnbrack, M. Binder, W. Woiwode**). A source that has attracted renewed attention has been local instability: several studies, using both observations and modelling, emphasized secondary generation, as a potentially important source (**E. Becker, S. Vadas**), where the breaking of a primary gravity wave causes local momentum deposition, the resulting body forcing exciting secondary waves. More generally, instability as a gravity wave source (**T. Mixa, K. Sato, M. Amiramjadi, A. Doddi**) means sources may be distributed across a broad range of altitudes, which is a shift away from current parameterization methods that place sources in the troposphere.

Propagation and parametrizations

An essential topic for gravity wave research concerns their parameterizations in weather and climate models. These parameterizations are indeed vital for the circulation of the middle atmosphere, both for climatology (time-zonal mean circulation), its variability (sudden stratospheric warmings) and key features such as the Quasi-Biennal Oscillation (QBO), which contributes to predictability on sub-seasonal to seasonal timescales. Lateral propagation of waves has received considerable attention, as a process well-identified from modelling and observations (**S. Rhode, M. Geldenhuys, L. Krasauskas**) but absent by construction from most parameterizations. Novel approaches that include lateral propagation in parameterizations were presented (**Y.-H. Kim, R. Eichinger**). Other limitations of GW parameterizations that are probed concern the assumption of stationarity (**G.S. Völker**), and the design of multiscale/scale aware parameterizations (**A. van Niekerk**). A fundamental difficulty encountered in the evaluation of parameterizations is the interplay and possible compensation between resolved and parameterized waves (**A. Gupta, P. Sacha, V. Yudin**). It has been proposed to use resolved waves to estimate the fluxes from unresolved waves (**H. Liu**). Increasingly, the issue of the signatures, impacts, and modelling of gravity waves in the upper mesosphere and beyond are being investigated (**C. Cullens, V. Avsakisov, R. Wing**). Combinations of observations from multiple satellite instruments allow us to quantify GWs "from the surface to the edge of space" (**N. Hindley**).

An important trend concerning parameterizations is the use of machine learning approaches, as in other fields of climate sciences. Machine learning with an appropriate training dataset allows us to reconstruct orographic wave patterns and momentum fluxes (**S. Watanabe**). Much coordination is being carried out within the DataWave project (**A. Sheshardi**), with encouraging preliminary results concerning emulation of existing schemes (**L. Yang, D. Connelly**).

Impacts

Current research was also presented discussing how gravity waves impact upon and drive the atmospheric system, across a range of heights and scales. A wide variety of topics were covered, demonstrating the increasing importance of accurately simulating GW-driven processes in models at all scales. Several talks discussed the direct dynamical impact of GWs. Measurements using both US (**T. Ehrmann**) and German (**P. Rodriguez Imazio**) specialist aircraft were presented demonstrating the generation of clear-air turbulence by GW breakdown, the scales that this wave-driven turbulence operates at, and how background flows affect this generation. At broader atmospheric scales, meanwhile, recent work was presented on interactions between sudden stratospheric warmings and gravity waves (**B. Thurairajah, H. Okui**) showing that GWs play important roles in both the descent of the stratopause and subsequent surface impacts, and on the formation of mesospheric inversion layer and an elevated stratopause. Work was also presented on the role of gravity waves generated in the middle atmosphere in long-range inter-hemispheric coupling via the meridional circulation (**K. Sato**), on compensation between planetary and gravity waves for the control of stratospheric drag (**J-H. Yoo**), and on how gravity wave dissipation and driving in the mesosphere directly control the circulation and also trigger in-situ turbulence (**M. Kohma**). Several talks also focused on the role of GWs in cloud formation, ice nucleation, and broader chemical transport in the middle atmosphere, and the role of gravity waves in monsoon rainfall. This included studies of polar stratospheric (**I. Krisch**) and mesospheric (**G. Baumgarten**) clouds and cirrus generation around the tropopause (**S. Dolaptchiev**), together with work on the interaction of gravity waves and monsoon winds over India to control diurnal convection (**R.T. Konduru**). Work was also presented clarifying the role of gravity wave drag in controlling mixing (**L. Holt, M.V. Guarino**). These studies show further evidence of the important roles of gravity waves in atmospheric chemistry and the control of weather systems and demonstrate that these processes are still not well-modelled.

Finally, a significant focus was on the effects of GWs on the QBO, with talks on this theme ranging from reanalysis-driven parameterisation schemes (**M-J. Kang**) and specialised novel parameterisations (**Y-H. Kim**) through to the detailed exploitation of in-situ balloon measurements to better constrain the waves that drive the cycle (**M.J. Alexander, M. Bramberger**). These talks highlighted that accurate simulation of how GWs drive the QBO requires high vertical resolutions, as the relevant waves are at very short vertical scales, and that convective GWs played an important role in the two recent QBO disruptions. The important role of GWs in driving the semi-annual oscillation above the QBO was also demonstrated, with comparisons between reanalysis winds and satellite observations showing that this forcing is too weak in free-running global climate models (GCMs, **M. Ern**).

Laboratory and ocean

Fundamental issues of GW dynamics can also be investigated via laboratory experiments. Several challenges have had to be overcome to achieve measurements of spontaneously generated GW in a differentially heated rotating annulus (**C. Rodda**). Results on the instability of internal gravity wave beams were also presented (**U. Harlander**). Stimulating new experimental concepts are being imagined, such the original use of a gas centrifuge to obtain a stratification (**M. Schlutow**). The dynamics of GW in the ocean was also present, with a special focus on lee waves (**C. Eden, Y. Wu**).

Discussion

A stimulating discussion concluded the meeting on Friday morning. The importance and relevance of collaborative efforts bringing together observational and modelling approaches, as in the MS-GWaves project, in International Space Science Institute (ISSI)-Team or in the starting DataWave project, was emphasized. Some of the difficulties tied to central issues on GW are highlighted, such as the comparison of different parameterizations, the creation and sharing of huge high-resolution model datasets, the challenge to maintain and improve the observational record (**P. Preusse**), the choice of criteria to evaluate parameterizations, or the difficulty to model and observe generation of GW from local instabilities. With modelling capabilities having considerably increased, and the relevance of an intercomparison of different approaches for parameterizations, the idea of a Gravity Wave Model Intercomparison Project is proposed and open for discussion. The discussion ended on the open question of the frequency of the SPARC Gravity Wave Symposium, with a generally enthusiastic reaction to a shorter interval between these meetings, of three rather than five years.

Figure 18: *Participants of the Gravity Wave Workshop, March 2022 near the Conference Center of the Evangelische Akademie.*

Report on the 8th HEPPA-SOLARIS Workshop

Hilde Nesse Tyssøy[1], Ville Maliniemi[1], and Bernd Funke[2]

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Dates:
13-15 June 2022

Organizing Committee:
Hilde Nesse Tyssøy, Chair, Scott Bailey, Bernd Funke, Kuni Kodera, Daniel Marsh, Katja Matthes, Jerry Meehl, Cora Randall, Craig Rodger, Pekka Verronen

Meeting venue:
Birkeland Centre for Space Science, Dept. physics and technology, University of Bergen, Norway

Number Of Participants: 45

Event Website:
http://solarisheppa.geomar.de/solarisheppa/

Sponsors:

Introduction

The 8th HEPPA-SOLARIS Workshop was held 13 - 15 June 2022 in Bergen, Norway. The focus of the 8th HEPPA-SOLARIS workshop was on observational and modelling studies of the influences of solar radiation and energetic particle precipitation on the atmosphere and climate. The workshop was comprised of 5 sessions with presentation around the following themes:

- solar and precipitating particle variability;
- solar photon and particle effects on the stratosphere and above;
- dynamical processes influencing the coupling of altitude regions;
- solar and particle effects on the troposphere and climate system; and
- tools for assessing solar and precipitating particle influences.

There were 48 presentations including 12 posters and participants from twelve countries (USA, Norway, Denmark, Finland, Spain, Germany, Switzerland, Poland, Belgium, Turkey, Israel, Japan) attended the workshop.

After a short welcome by the local organizing committee (chaired by **Hilde Nesse Tyssøy**), **Gabriel Chiodo** gave a tribute talk in memory of William Ball. Despite his young age, Will, has played an important role for our understanding of e.g., solar forcing on ozone variability. Moreover, his networking capability and inclusive personality, have made a long-lasting imprint on the cross-disciplinary field that the HEPPA-SOLARIS community represents. An article on his great work can be found on page 42.

Solar and precipitating particle variability

The first session on "Solar and precipitating particle variability" started with an invited presentation by **Allison**

Jaynes on the contribution of high-energy pulsating aurora to the total energetic particle precipitation content. She emphasized the link between substorm injections and a higher level of energy transfer from the radiation belts to the atmosphere system. The importance of pulsating aurora on the precipitation budget was substantiated by the next speaker, **Noora Partamies**. She showed that pulsating aurora is a dominant phenomenon in the morning sector and an important dissipation mechanism. **Eldho Midhun Babu** presented a new model to determine the latitudinal extent of the equatorward boundary of the precipitation region. **Emma Bland** discussed the spatial evolution of the substorm energetic electron precipitation region utilizing a network of riometer and SuperDARN measurements. **Josephine Salice's** research focused on solar wind drivers and their effects on the high-energy tail of the precipitating energetic electron spectrum. **Hilde Nesse Tyssøy** demonstrated how the predictive capabilities of the Auroral Electrojet (AE) index for medium energy electron precipitation increased when implementing the preceding geomagnetic activity. **Gang Li** talked about solar energetic particles and their solar cycle dependence wherein their model simulation results may improve our understanding of historical climatic events. In the poster session **Haakon Dahl Eide** presented a preliminary intercomparison study of auroral electron precipitation observations and models. **Pelin Erdemir** discussed the relationship between magnetohydrodynamic (MHD) model Joule heating and interplanetary coronal mass ejection parameters. **Ezgi Gülay** investigated ionospheric and ground level effects of space weather over Turkey.

Maliniemi showed how the influence of energetic particle precipitation has affected stratospheric chlorine and ozone over the 20th century. **Jia Jia** presented preliminary results on Bromine species response to particle precipitation. **Niilo Kalakoski** and **Thomas Reddmann** both evaluated the chemical impact on solar extreme events on the middle atmosphere, while **Timofei Sukhodolov** showed a case study of where balloon measurement detected exceptionally strong middle latitude electron precipitation and evaluated the implication on atmospheric composition. The invited talk by **Lynn Harvey** explained the role of the polar vortex in Sun-Earth coupling via the descent of EPP-produced NOx alongside outstanding challenges on NOx transport. Similarly, **Patrick Espy** highlighted the role of tides in the downward transport of NOx. **Timo Asikainen** pointed out that the EPP ability to affect the stratospheric polar vortex dynamics is linked to the planetary wave propagation. **Hector Daniel Zuniga Lopez** demonstrated that medium energy electrons might have the ability to change the mesospheric dynamics directly during a sudden stratospheric warming event. In the poster session **Antti Salminen** further highlighted the role of planetary waves in modulating the EPP impact on the northern hemisphere polar vortex, while **Mikhail Vokhmianin** discussed how this new knowledge could affect long-term prediction of sudden stratospheric warmings. **Miriam Sinnhuber** presented the impact of an extreme solar event on atmospheric composition, stratospheric dynamics, and surface temperatures. **Ingrid Mann** investigated polar mesospheric summer echoes during nighttime late summer conditions.

Solar photon and particle effects on the stratosphere and above/dynamical processes influencing the coupling of altitude regions

Session two and three, "Solar Photon and Particle Effects on the Stratosphere and above" and "Dynamical Processes Influencing the Coupling of Altitude Regions", were merged into multiple presentations that covered both topics. The session started with **Miriam Sinnhuber** giving an overview of the HEPPA III intercomparison experiment on electron precipitation and impact, pointing out remaining challenges both in terms of the forcing as well as model limitations. **Ville**

Solar and particle effects on the troposphere climate system including atmosphere and ocean-atmosphere coupling

The invited talk of **Hanli Liu** initiated Session 4 on "Solar and Particle Effects on the Troposphere Climate System Including Atmosphere and Ocean-Atmosphere Coupling". **Hanli Liu** addressed robust climate responses to extreme solar minimum forcing and their hemispheric differences. **Wenjuan Huo** discussed our understanding of the transfer of the solar signal from the stratosphere to the troposphere. The invited talk by **Tobias Spiegl** highlighted the twenty-first century climate change hotspots considering a weakening Sun. Moreover, **Annika Drews**, also invited, focused on the Sun's role for decadal climate prediction in the North Atlantic. **Chaim Garfinkel** used a simplified aqua planet model to unravel how the top-down mechanism in the northern hemisphere winter responds to solar UV radiation. **Jan Sedlacek** discussed the influence of solar irradiance on future climate. **Gabriel Chiodo** revisited the solar influence on North Atlantic winter climate. The poster presented by **Tobias Spiegl** addressed the sensitivity of the tropical Pacific decadal climate variability to anthropogenic and solar forcing in a chemistry-climate model ensemble. While most of the presentations were based on model simulations, **Lon Hood** applied empirical data to illustrate the QBO and solar influence on the equatorial lower stratosphere. The session was completed with **Jose Tacza** focusing on energetic particle effects on the atmospheric electric field in fair-weather regions. **Jone Edvartsen** demonstrated the need for robust statistical significance testing and the role of autocorrelation evaluating the Mansurov effect.

Tools for assessing solar and particle influences, including measurements, models, and techniques

The last session focused on "Tools for assessing solar and particle influences, including measurements, models, and techniques". The invited talk by **Yoshizumi Miyoshi** highlighted how coordinated observations of the Arase satellite and European Incoherent Scatter Scientific Association (EISCAT) in Tromsø could unravel the relativistic electron precipitation associated with pulsating aurora. The invited talk by **Ales Kuchar** addressed methods relevant for the attribution of solar activity in the stratosphere and above. Moreover, **Tarkan Bilge** discussed the use of generalized additive models for investigating signals of solar influence. **Maryam Ramezani Ziarani** presented the ozone and net radiative heating changes induced by energetic particle precipitation and ultraviolet solar variability in the ICON-ART-LINOZ climate model with linearized ozone chemistry. **Toralf Renkwitz** used the data from the Saura radar on Andøya to assess the variability of polar D region ionization near the solar minimum of cycles 24/25.

Robert Marshall presented the plans for the Atmospheric Effects of Precipitation through Energetic X-rays (AEPEX)CubeSat Mission, followed by **Grant Berland** addressing the method of turning bremsstrahlung photon counts into energetic electron precipitation data. **Stefan Bender** gave a talk on empirical modelling of Special Sensor Ultraviolet Spectrographic Imagers (SSUSI) derived auroral ionization rates, while **Charlotte van Hazendonk** demonstrated how cutoff latitudes of solar proton events measured by GPS satellites aligned with previous methods. In the poster presentations **Zheyi Ding** modeled the 2020 November 29 solar energetic particle event using the EUropean Heliospheric FORecasting Information Asset (EUHFORIA) and the improved Particle Acceleration and Transport in the Heliosphere (iPATH) model, while **Tuomas Häkkilä** presented the atmospheric impact of auroral electrons in WACCM-D simulations with eVlasiator input. **Hilde Nesse Tyssøy** emphasized the main findings of HEPPA III intercomparison experiment for the eight different ionization rate estimates during a geomagnetic active period in April 2010. **Bernd Funke** presented future potential prospects for the Earth Explorer 11 candidate Changing-Atmosphere Infrared Tomography Explorer (CAIRT) mission.

SOLARIS-HEPPA working group meeting

On the following one and a half days (16 and 17 June 2022), the SOLARIS-HEPPA working group meeting was held at the University of Bergen in a hybrid format with 17 in-person and 21 remote participants. The meeting had three sessions with oral presentations and topical discussions related to proposals for new SOLARIS-HEPPA working groups.

The first session focused on solar surface climate impacts and decadal predictability. **Wenjuan Huo** presented plans for a dedicated working group on this topic. This was followed by a discussion about specific model experiments to be designed and analysed by this new working group. **Chaim Garfinkel** proposed to investigate, in collaboration with the Stratospheric Network for the Assessment of Predictability (SNAP), the benefit to surface predictability that would be gained by including a representation of the solar rotational period in a forecasting model. The discussions were followed by two talks. **Lon Hood** examined the representation of extra-tropical wave forcing in CMIP6 climate models and highlighted its relevance for a realistic simulation of solar cycle variations of the tropical lower stratosphere. **Kleareti Tourpali** presented an analysis of solar cycle variations in stratospheric ozone and temperature from CCMI-2022 REF-D1 simulations in comparison to satellite observations.

The second session addressed the solar forcing by solar irradiance variability and energetic particle precipitation, including direct chemical impacts. A special focus was given to efforts towards revised solar forcing recommendations for CMIP7. **Miriam Sinnhuber** assessed the strengths and weaknesses of currently available energetic particle forcing datasets. **Timo Asikainen** presented a new long-term ionization dataset based on POES data. **Stefan Bender** provided more details about the SSUSI ionization model. After these three talks, potential improvements of energetic particle forcing data sets for CMIP7 were discussed. This was followed by a talk by **Odele Coddington** about recent improvements since CMIP6 of the absolute magnitude and variability of total and spectral solar irradiance. **Miriam Sinnhuber** presented plans for a new HEPPA-4 inter-comparison activity focussing on the assessment of the forcing by auroral electron precipitation and its representation in high-top models.

The last session was dedicated to the assessment of existing statistical approaches to analyse solar signals in model and observational data. **Ales Kuchar** provided an update of on-going activities within the SOLARIS-HEPPA working group on 'Methodological Analysis', which was followed by a discussion about future plans of these working groups and potential synergies with SPARC activities Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) and Atmospheric Temperature Changes and their Drivers (ATC).

Acknowledgements

We would like to thank WCRP/SPARC for its support, as well as sponsorship from Birkeland Centre for Space Science and University of Bergen (the host institution). We especially thank the local organising committee for an excellent venue and the organisation of the meeting.

Figure 19: *Participants of the 8th HEPPA-SOLARIS workshop held in Bergen, Norway.*

In memory of Professor Masato Shiotani

Shigeo Yoden

Kyoto University, Japan

Figure 20: *Professor Masato Shiotani.*

Professor Masato Shiotani (Figure 22) passed away on February 9, 2022, at the age of 63. He was a professor and the director of the Research Institute for Sustainable Humanosphere (RISH) at Kyoto University (KU). Masato Shiotani was born in Toyama Prefecture in 1958, graduated from the Faculty of Science, KU in 1982, and completed the doctoral program in 1987 under the supervision of Professor Isamu Hirota, receiving a Doctor of Science degree from KU. In the same year, he was hired as an assistant professor at the Faculty of Science, KU. After promotion to associate professor in 1995 and full professor in 1998 at the Graduate School of Environmental Earth Science, Hokkaido University, he was promoted again to a professor at the Radio Science Center for Space and Atmosphere (RASC), KU in 2001. In 2004, he was reassigned as a professor at the RISH reorganized from RASC, and in 2020 he was appointed as its director. For over a year from 1985, he was sent to NCAR as an overseas research student and started his international research career under the supervision of Dr. John Gille. He stayed at NCAR another year in 1992-1993 as a fellow for research abroad of the Ministry of Education to study middle atmosphere dynamics by analyzing environmental information observed by satellites. This time, Masato Shiotani was awarded The Order of the Sacred Treasure, Gold Rays with Neck Ribbon for his outstanding achievement in "Research on dynamical processes in the middle atmosphere based on analyses of global satellite observation information and field observations mainly in tropical regions".

Masato Shiotani has been studying the general circulation of the lower and middle atmosphere, mainly in terms of atmospheric dynamics and transport processes of trace constituents, based on data analyses of global satellite observations and gridded meteorological analysis datasets. In 2002, he received the Meteorological Society of Japan Award jointly with Professor Fumio Hasebe for their "Research on spatiotemporal variations and dynamical processes of stratospheric ozone distribution in the equatorial region". Since 1998, they and their colleagues have conducted field observation campaigns in the tropical Pacific as the Soundings of Ozone and Water in the Equatorial Region (SOWER) Pacific Mission. The mission aims to better understand the distribution and variability of ozone and water vapor in the troposphere and stratosphere, and they have obtained new knowledge of the mass exchange processes through the tropical tropopause layer and observationally clarified the controlling processes of water vapor concentration in the layer. Later, he became the Principal Investigator of the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) in the Japanese Experiment Module on the ISS, which was launched in 2009, and conducted high-sensitivity observations firstly using a superconductive low-noise receiver with a mechanical 4-K refrigerator in space. It was the first to detect several radical species of halogen chemistry related to ozone destruction.

Masato Shiotani has published about 110 peer-reviewed articles in his whole research career. Keyword search in a publication database tells us some numbers of papers that include the following keywords: ozone 59, SMILES 37, water vapor 29, SOWER 7; tropics 49, global 38, polar 21; data 70, analysis 28.

In education, Masato Shiotani has served as the supervisor for five doctoral students and a secondary reviewer for 18 doctoral students in the Graduate School of Environmental Earth Science, Hokkaido University, and the Graduate School of Science, KU.

He also served as the program coordinator for Inter-Graduate School Program for Sustainable Development and Survivable Societies, KU. This inter-graduate school program fosters global human resources that pioneer the newly emerging interdisciplinary field "Global Survivability Studies" and contribute to the safety and security of the world, under the cooperation of nine graduate schools and three institutions, including RISH, at KU. Furthermore, together with local researchers, he had held the "Atmospheric Chemistry Study Group" for graduate students and young researchers nine times since 1999, inviting up-and-coming researchers from Japan and abroad, and contributing to the capacity development of young researchers in this field.

Based on his experience with the computer environment at NCAR in the 1980s, he participated in the establishment of the GFD-Dennou Club and has been a core member of the administration group since its inception, exploring and building a close relationship between earth science and computational and computer sciences, through automation of observations and experiments, data analysis, and numerical model experiments and simulations. He has greatly contributed over three decades to developing and maintaining the GFD-Dennou Club Library, which is a Fortran library for graphics, text processing, and basic numerical processing, to promoting the Davis Project for structuring and visualization of multidimensional data by an object-oriented scripting language, Ruby, and to maintaining earth science databases, including RISH database.

His prominent international activities include serving on the WCRP/SPARC Scientific Steering Group (2009-12). He hosted the 17th SPARC SSG meeting at KU in October 2009 (Figure 23). Also, he co-chaired the local organisation commitee of the 6th SPARC General Assembly held in Kyoto on October 1-5, 2018 in which 382 participants gathered even under the influence of tropical cyclones that hit Kyoto twice in September. He has also served as a member of the IUGG/IAMAS International Commission on the Middle Atmosphere and the International Ozone Commission, and contributed as a co-author to the writing of a sequence of reports on "Scientific Assessment of Ozone Depletion" sponsored by WMO/UNEP.

Masato Shiotani will be greatly missed by his wife and daughter, friends, colleagues, and students. A memorial symposium was held at Obaku Plaza, Kihada Hall on Uji Campus, Kyoto University, on the 13th of June 2022. His colleagues and students had gathered in situ and online to share his achievements and memories with his family.

Figure 21: *Groupfoto of SPARC SSG Members at the 17th SSG Meeting at Kyoto University 2009.*

In memory of William Ball

Thomas Peter[1], Nir Bluvshtein[1], Gabriel Chiodo[1], Andrea Stenke[1], and Louise Harra[2]

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Figure 22: *Will Ball during "The 25 Years of International SPARC Research Symposium", held in Zürich on 1 December 2017.*

Our colleague and friend Will Ball died at the age of 39.

Scientifically curious, sharp-witted, open-minded, honest, warm-hearted, and with a great sense of humour! That's how many of us would describe Will Ball, by the first impression he left us with that endured over time. Will's commitment to both science and to his colleagues has been an inspiration to many. Sadly, he left us forever on 29 April 2022-far too soon.

Dr. William T. Ball received his University degree in Physics and Mathematics from the University of Durham. He was then awarded a PhD in Astrophysics from the Imperial College in London. His dissertation, entitled "Observations and Modelling of Total and Spectral Solar Irradiance", focused on magneto-hydrodynamic modelling of solar irradiance variability on daily to centennial time scales. From there, he moved on to Switzerland and to investigating the impact of irradiance changes on the Earth's stratosphere and the ozone layer. Will pursued this topic for about five years, from 2014 to 2019, at both the Institute for Atmosphere and Climate Science at ETH Zurich and the Physical Meteorological Observatory in Davos (PMOD). In 2019, Will received an appointment as an Assistant Professor in the Department of Geosciences and Remote Sensing at TU Delft and as a Visiting Scientist at KNMI in De Bilt, both in the Netherlands. Within a few months of arrival, Will was diagnosed with cancer.

His most influential achievement received widespread, international media attention in February 2018. He led an international research team that developed new algorithms that are arguably the most advanced means of reducing uncertainties in ozone composite data. This led to the discovery that-despite the undoubted success of the Montreal Protocol on Ozone Depleting Substances-ozone in the lower stratosphere had continued to decline at middle and tropical latitudes, where the vast majority of the world's population lives. The response from the atmospheric community came promptly. Some scientists doubted the findings, as most global chemistry-climate models did not show such a sustained, worrisome decline. Others started to investigate possible reasons for the decline; a question that has developed into a major topic of research for the wider scientific community. Will's outstanding contributions were crucial in assessing the ozone response to the 11-year solar cycle, resolving previous discrepancies across ozone composites, which led to his involvement in LOTUS - Long-term Ozone Trends and Uncertainties in the Stratosphere, one of many research activities of SPARC and led by the World Climate Research Programme. He also recently became involved in the WMO UNEP Ozone Assessment, the most influential report on the status of the ozone layer.

His recent work also addressed the controversy in new estimates of spectral solar irradiance, which indicated that solar cycle variability may be

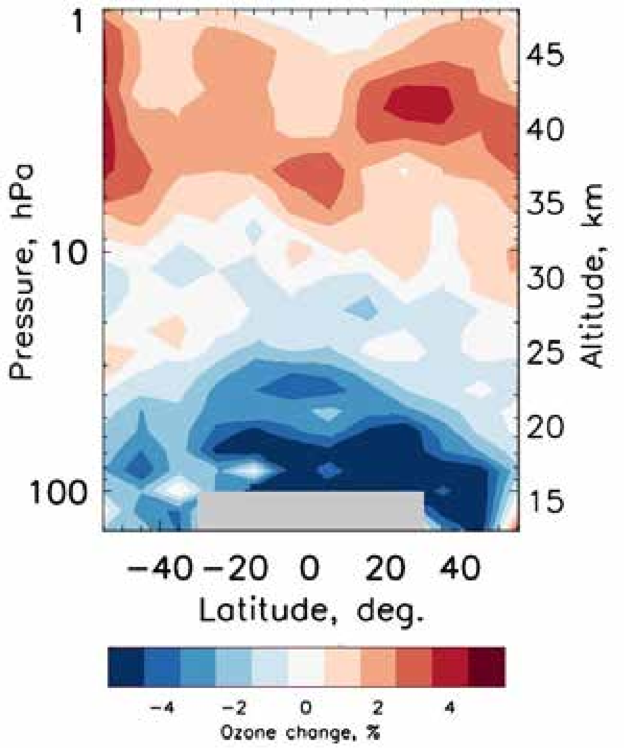

Figure 23: *Zonally averaged change in ozone between 1998 and 2016 (Merged-SWOOSH/GOZCARDS composite). Red represents increases, blue decreases (%; see color bar). Grey shaded regions represent unavailable data. From: Ball et al. (2018).*

up to ten times larger than previously suggested by models and earlier observations. Through a novel approach combining ozone and solar irradiance science, he resolved the controversy by demonstrating that these large solar cycle irradiance changes are incompatible with ozone observations. This led Switzerland to nominate him in 2016 as Young Scientist of the Year to the World Meteorological Organization.

In October 2021, Will was awarded the "Dobson Award for Young Scientists" from the International Ozone Commission for his outstanding scientific achievements in atmospheric sciences and in recognition of his three articles entitled:

- "Evidence for a continuous decline in lower stratospheric ozone offsetting ozone layer recovery" (Ball *et al.*, 2018),
- "Stratospheric ozone trends for 1985–2018: sensitivity to recent large variability" (Ball *et al.*,2019),
- "Inconsistencies between chemistry–climate models and observed lower stratospheric ozone trends since 1998" (Ball *et al.*,2020).

With his commitment and dedication, Will has had a significant impact on the ozone and stratospheric research communities, opening new research avenues and spurring valuable discussion.

We, as Will's colleagues in Switzerland, were privileged to work and spend time with him during a creative and productive chapter of his career. But most of all, we had the privilege of his friendship; his passion, dedication, and ability to bring people together will always serve as a true inspiration to us. Will, we thank you for the positive impact you've had on our lives, both professionally and personally. In thinking of you and your good sense of humor, we imagine you sitting up there together with Gordon Dobson and Alan Brewer, looking at our planet and at what we are doing, partly excited and partly amused. You will always be remembered and your scientific legacy will live on in our work.

For all of Will's colleagues at ETH and PMOD.

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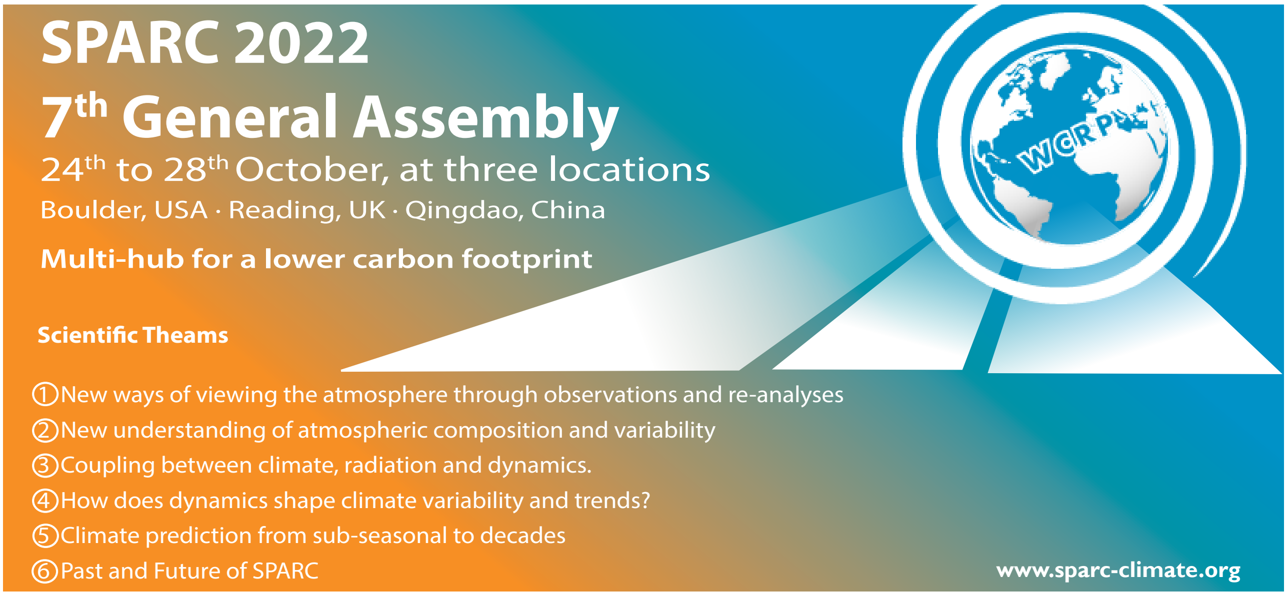

SPARC meetings

10th - 15th September, 2022
iCACGP-IGAC2022 Hybrid Conference
Manchaster, UK & online

26th - 30th September, 2022
Meteorology for Climate Actions
online

24 - 28 October 2022
7th SPARC General Assembly
China, UK, and USA

SPARC related meetings

28 August - 02 September 2022
20th Swiss Climate Summer School Extreme weather and climate: from atmospheric processes to impacts on ecosystems and society
Grindelwald, Switzerland

25 - 29 September 2022
SOLAS Open Science Conference
Cape Town, South Africa

26 - 30 September 2022
BIPM-WMO Workshop on Metrology for Climate Action
online

17 - 19 October 2022
2nd Climate Observation Conference
Darmstadt, Germany

31 October - 4 November 2022
6th WGNE Workshop on Systematic Errors in Weather and Climate Models
Reading & online

12 - 16 December 2022
Metrology for CIAGU Fall Meeting
Chicago, USA & online

8 - 12 January 2023
103nd AMS Annual Meeting
Denver, USA & online

23 - 27 October 2023
WCRP Open Science Conference
Kigali, Rwanda

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

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