SPARC
Stratosphere-troposphere
Processes And their Role in Climate

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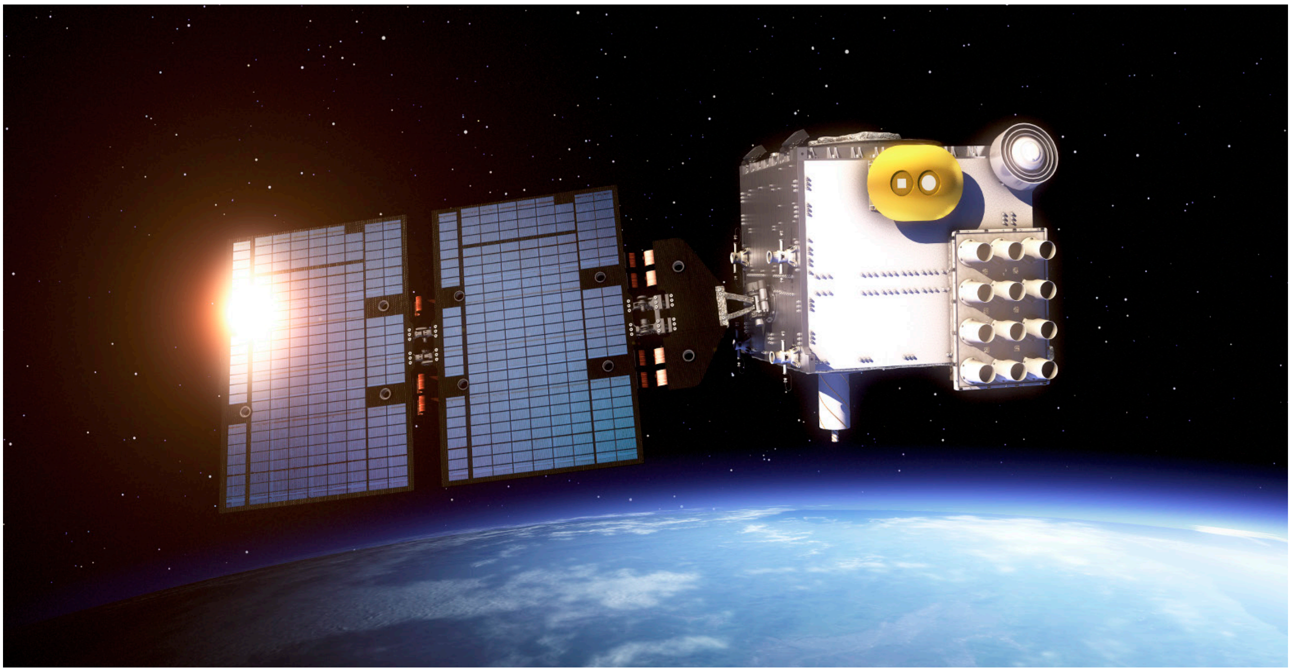

The Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC-2) is an operational mission following the successful COSMIC-1 mission launched in 2019. On this satellite program, NOAA is partnering with the U.S. Air Force (USAF), Taiwan's National Space Organization (NSPO), and the University Corporation for Atmospheric Research (UCAR).

A constellation of six satellites with next generation Global Navigation Satellite System Radio Occultation (GNSS-RO) receivers, COSMIC-2 collects atmospheric data for weather forecasting, climate monitoring, and space weather research. RO data was analysed by SPARC's atmospheric temperature trends activity and combined with data from radio soundings to derive temperature variability and trends between 1979 and 2018 (see article on page 11).

Image credit: Surrey Satellite Technology Ltd.
https://www.nesdis.noaa.gov/COSMIC-2; https://www.cosmic.ucar.edu/what-we-do/cosmic-2/

Contents

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

A new SPARC strategy for the next 5-10 years

Amanda Maycock[1], Mareike Heckl[2] , and the SPARC Strategy Task Team

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SPARC is in the process of developing its new strategy for the next 5 - 10 years, during a time of reorganization of the World Climate Research Programme (WCRP). To look ahead to the future challenges and opportunities for SPARC, a task team was formed in October 2020 to consult across the SPARC community and beyond. The task team is led by Amanda Maycock (Univ. of Leeds, UK), and its 22 members represent the SPARC community with respect to science topics, geography, gender, and career stage. The team also includes representatives from IGAC and YESS, as well as other connected WCRP panels and programmes. Adding more representatives from partner projects is currently being organized. The focus of the task team has been to review the current SPARC structure, its strengths and weaknesses, and to discuss possible future science topics that fall within the new WCRP strategic plan, and an implementation plan for the future SPARC.

WCRP started a soft transition to its new structure in January 2020 (see overview on page 5). As part of the reorganization, the core projects were asked to review themselves internally, to make sure they will fit into the new WCRP. An online SPARC Scientific Steering Group meeting, with task team representatives, was held in November to present interim findings, consult with the SPARC leadership, and provide an opportunity for community information and input to the task team discussions. The first results of the task team discussions were presented at an extraordinary session of the Joint Scientific Committee (JSC-41B) in December, to inform the WCRP leadership about the progress of the task team and the SPARC internal review.

Review of the current structure

The task team have so far held 3 video conference sessions each for the "Western hemisphere subgroup" and the "Eastern hemisphere subgroup". During these discussions, the task team members assessed the current state of SPARC, and found that:

- SPARC is positioned at the interface of the weather and climate communities – bridging WCRP and WWRP.
- SPARC consists of bottom-up activities and plays a strong role in building up (new) communities.
- SPARC is a facilitator of good research.
- SPARC is able to advocate towards policy makers and funding agencies.

With its long history, SPARC is well established in the research community and provides an environment that encourages focused research activities. However, there was a perception amongst the task team that SPARC could be bolder about its achievements and excellence within WCRP and externally, to raise its profile further. The existing structure, with dedicated activities working on a variety of research topics, is seen as a success. The task team recommends that activities working on focused topics should still be encouraged, but where appropriate there should be a push to take on the whole-atmosphere approach more comprehensively – as requested by the WCRP leadership. The bottom-up approach of most activities should be kept as it plays an important part in community building, but some top-down organization might be required, for example to streamline work (possibly by merging some activities), or to implement short-term work on focused topics that may be needed to feed into the developing WCRP Lighthouse Activities. The activity-based structure of SPARC provides flexibility to maintain different natures of activities (*e.g.*, report oriented, network oriented, *etc.*), which should be kept in the future.

Going forwards, the SPARC community are well positioned to provide dynamical insights into modeling studies and technical support for model analysis, to collect code basis, data, open-source tools and make them accessible; even develop a community diagnostic tool for dynamics. SPARC should remain agile and be ready to take the lead in emerging science areas (*e.g.*, machine learning or data science topics). All those activities will contribute to the planned WCRP Lighthouse Activities. The SPARC community already distributes knowledge through workshops and training, but there are further opportunities for capacity building and supporting early career scientists (see Outreach, below).

As an advocate towards policy makers, the task team sees SPARC in a leadership role to make sure efforts are not "forgotten" or "lost on the way", to maintain and advance long-term climate records for large assessments (IPCC, WMO/UNEP Ozone, *etc.*) and mission planning. SPARC scientists can contribute to addressing local impacts of climate change, and are well equipped to communicate and advise on new science areas, such as solar radiation management in the context of geoengineering.

Outreach

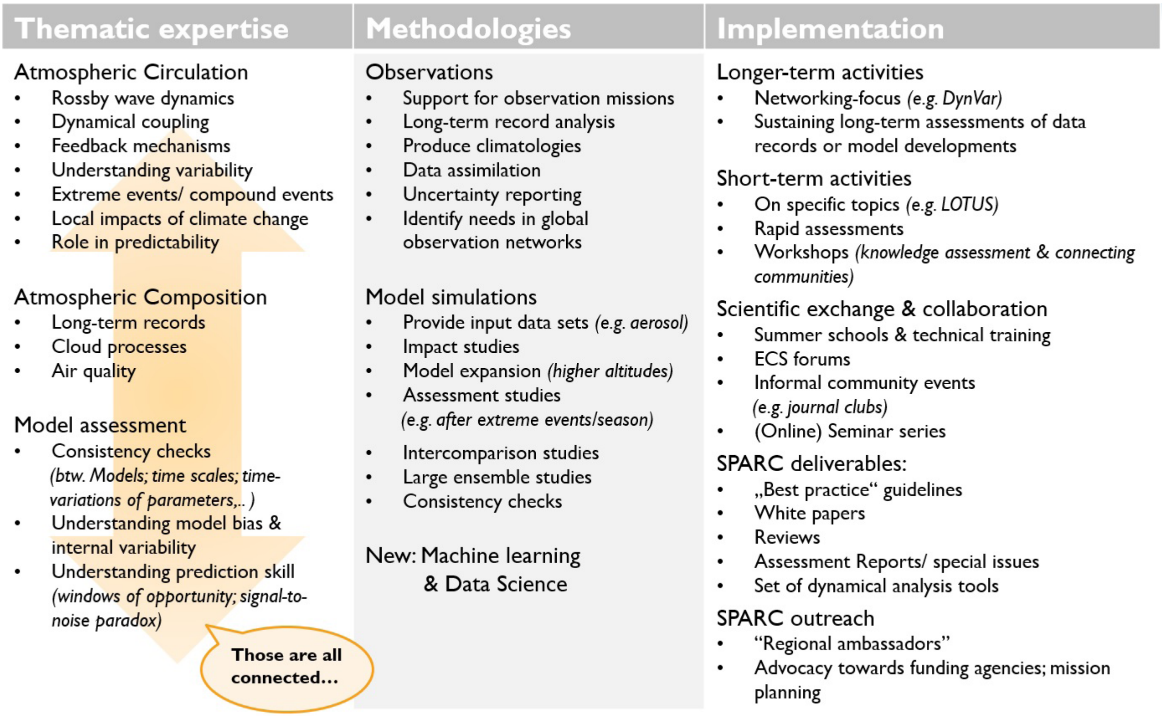
The task team identified a need for more and different ways to engage with early career scientists, as well as with other research communities. Capacity building will stay within the focus of SPARC, to make sure future members of the community are equipped with the necessary tools and knowledge to contribute. The engagement with regional communities was seen as a key issue. Existing and new WCRP activities may help with this, but as an addition, the idea of installing "regional ambassadors" for SPARC to engage with local communities, identify their needs, and communicate research results was discussed by the task team.

Overall, the task team identified a need to have room to more "informally" create groups and networks. In particular, the rapid increase in virtual platforms in the last year provides new opportunities for engagement at local and global scales. This could mean one-off workshop opportunities to connect with existing research groups to facilitate regional and thematic expansion. Having less reporting requirements may encourage more community engagement (e.g. through small, local groups), which could also provide a basis for more early career researcher engagement, as this provides an opportunity to build something new in their communities. An early career "forum" was also discussed to present latest work in a more informal environment. This could be in parallel to, or as part of the new WCRP Academy.

Ideas for future SPARC functions

SPARC provides many key functions to the wider scientific community. This includes the hosting of workshops on specific topics. In the future, SPARC can seek opportunities for joint workshops that cut across the WCRP core projects. The 2019 joint SPARC/CLIVAR/GWEX workshop on heat storage in the Earth System was cited as a good example of a focused workshop with strong collaboration between partner projects. Next to the more traditional workshops, a variety of other options are available, including online seminars, a platform to share the latest results, as well as informal workshops with no dedicated result, except bringing together the communities.

SPARC communities are well placed to contribute to and lead on reviews or position papers around emerging issues (e.g. future directions in geoengineering, machine learning, and causality study tools and methods).



Thematic expertise

Atmospheric Circulation
- Rossby wave dynamics
- Dynamical coupling
- Feedback mechanisms
- Understanding variability
- Extreme events/ compound events
- Local impacts of climate change
- Role in predictability

Atmospheric Composition
- Long-term records
- Cloud processes
- Air quality

Model assessment
- Consistency checks *(btw. Models; time scales; time-variations of parameters,..)*
- Understanding model bias & internal variability
- Understanding prediction skill *(windows of opportunity; signal-to-noise paradox)*

Methodologies

Observations
- Support for observation missions
- Long-term record analysis
- Produce climatologies
- Data assimilation
- Uncertainty reporting
- Identify needs in global observation networks

Model simulations
- Provide input data sets *(e.g. aerosol)*
- Impact studies
- Model expansion *(higher altitudes)*
- Assessment studies *(e.g. after extreme events/season)*
- Intercomparison studies
- Large ensemble studies
- Consistency checks

New: Machine learning & Data Science

Implementation

Longer-term activities
- Networking-focus *(e.g. DynVar)*
- Sustaining long-term assessments of data records or model developments

Short-term activities
- On specific topics *(e.g. LOTUS)*
- Rapid assessments
- Workshops *(knowledge assessment & connecting communities)*

Scientific exchange & collaboration
- Summer schools & technical training
- ECS forums
- Informal community events *(e.g. journal clubs)*
- (Online) Seminar series

SPARC deliverables:
- „Best practice" guidelines
- White papers
- Reviews
- Assessment Reports/ special issues
- Set of dynamical analysis tools

SPARC outreach
- "Regional ambassadors"
- Advocacy towards funding agencies; mission planning

Figure 1: *Overview of SPARC themes, methods, and implementation forms as seen by the SPARC Strategy Task Team.*

Furthermore, SPARC could act as a collector of tools; e.g., hosting a community code basis in style of, or cooperation with pangeo. This could be developed into a catalogue to find analysis tools online, creating a reference point for scientists looking for diagnostics and tools.

Further new forms of SPARC output may include guidance documents and white papers, guidelines of "best practices", and suitable information for outreach to society and policy makers, which requires a different approach than scientific reporting through journal publications or assessment reports. Surveys might be a useful tool to identify specific community and user needs.

Science topics

As an interim result of the task team discussions, an overview of research topics, methodologies, and implementation needs were presented to the SPARC SSG in the November online meeting (see Figure 1). This is not meant as a complete description of the SPARC project, recognizing that ongoing science and developments in societal needs may influence the growth of activities in the future. However, it does show the large variety of scientific topics already in the focus of the community, or possibly added under a new strategy, as well as the important methodological work the SPARC community delivers on a regular basis.

Important aspects of the expansion of future topics (adding to existing SPARC topics), as identified by the task team, include:

1) Moving towards the whole-atmosphere perspective

There was agreement in the task team that the transition of SPARC to 'Stratosphere-troposphere' processes has been of limited success. In particular scientists outside of the SPARC community still perceive its remit to be largely stratosphere focused. Going forwards SPARC science should more comprehensively include tropospheric weather and climate as well as higher altitudes. Knowledge of wave dynamics as a core expertise of the SPARC community could be utilized and expanded to help achieve this. Emerging tools, such as machine learning, should be applied to whole-atmosphere studies. Another scientific focus should be on local impacts of climate change, and the works on composition should be expanded.

2) Dynamical attribution and detection

SPARC science should work on the relation between extreme seasons or months to teleconnection patterns or anomalies. In this context, SPARC scientists could contribute to the growing field of event attribution which has societal and policy relevance. The dynamics behind climate extremes must be further understood. There is an important role of observations (both composition and dynamics) in this, as well as for the use of large ensembles in the whole-atmosphere context.

3) Predictability

Some SPARC activities already focus on this topic. New areas of research may include the identification of windows of opportunity for S2S and multi-year prediction, identification of untapped sources of predictability (including signals from higher altitudes), and understanding and predicting compound events and their impacts. In the context of the WCRP objective of "Science for society" seamless prediction and its application will play an important role. Machine learning and data science tools will be valuable tools in understanding and improving predictions.

4) Geoengineering: radiation management

This growing research topic needs expertise on composition and dynamics, specifically their links, which has traditionally been a strength of SPARC. SPARC's expertise in long-term records, and recognition of the important role of and advocacy for observations will be important for future scenarios. Collaborations with already existing communities will be key.

Many possibilities to connect to existing communities, and enhancing collaborations with partner projects are obvious from this list of future science topics. Working together with the other WCRP projects, and feeding into the WCRP light house activities will be an essential part of future SPARC work.

Further ideas and comments from the SPARC community are welcome, and can be submitted via email to the SPARC office. The task team will continue its work in 2021. The overall aim is producing a finalized SPARC strategy in time for the next session of the WCRP Joint Scientific Committee, to be held 28 June - 2 July 2021. As a next step, the upcoming Activity reporting meeting (28th SPARC SSG meeting – part II; 2nd and 9th February 2021) will be used to continue community involvement in the discussions. The task team will continue its discussions with the aim of giving to the co-chairs a comprehensive view of what the priority areas are and what they should be going forward, and how this should be organized in SPARC and linking in with other groups.

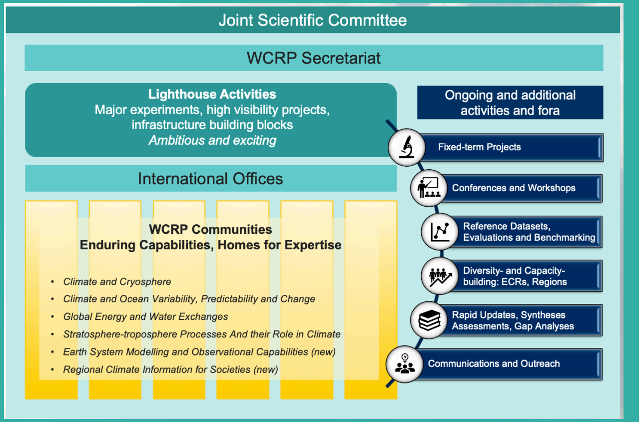
WCRP moving forward: What is "the new WCRP"?

Overview of the new WCRP elements and the way forward

The World Climate Research Programme (WCRP) is committed to pursuing – through international coordination – frontier scientific questions related to the coupled climate system that are too large and too complex to be tackled by a single nation, agency, institution, or scientific discipline.

While the Strategic Plan, introduced to the science community in 2019, provides the high-level view of the science, infrastructure, and collaborations needed to ensure our climate science will meet the knowledge and information needs of society; the WCRP 'Implementation Plan' will outline the future structure and elements of the Programme and outline how WCRP will achieve its mission and scientific objectives. After consultation and discussion with the WCRP leadership and community, two high-level research priorities were identified, that are called our "Implementation Priorities" to: 1) Foster and deliver the scientific advances and future technologies nd to 2) Develop new institutional and scientific approaches.

After extensive consultation with the WCRP leadership and some of the WCRP community, it was agreed at the Extraordinary Session of the Joint Scientific Committee in December 2020 to, in principle, move towards the new structure.



New WCRP structure as agreed on during the JSC-41B meeting in December 2020. SPARC will be one of the yellow pillars.

Some of the most exciting new ideas being developed as part of the new WCRP are the Lighthouse Activities (LHAs). They are intended to be major experiments, high-visibility projects, or infrastructure building blocks, and are meant to truly integrate the capabilities (scientific, technical, infrastructure) across WCRP and with partners. They are also expected to provide the science required by WCRP to deliver its outcomes, and to ensure that societal needs are being addressed, over the coming decades. The five proposed LHAs are:

1) Explaining and Predicting Earth System Change: To design, and take major steps toward delivery of, an integrated capability for quantitative observation, explanation, early warning and prediction of Earth System Change on global and regional scales, with a focus on multi-annual to decadal timescales.
2) My Climate Risk: To develop a new framework for assessing and explaining regional climate risk to deliver climate information that is meaningful at the local scale.
3) Safe Landing Climates: To explore the routes to climate-safe landing 'spaces' for human and natural systems, on multi-decadal to centennial timescales; connecting climate, Earth system, and socio-economic sciences. Explore present-to-future "pathways" for the achievement of key SDGs.
4) Digital Earths: To develop a digital and dynamic representation of the Earth system, optimally blending models and observations, to enable an exploration of past, present, and possible futures of the Earth system.
5) WCRP Academy: To establish one or more targeted capacity exchange climate programmes, working with one or more of the other lighthouses and established climate education providers, including universities.

WCRP is committed to engaging with all regions of the world. The WCRP Climate Research Forums will be aimed at engaging with the broader community and exchanging information and opportunities to further WCRP's vision, mission, and scientific objectives. To work with us on this journey, over 50 scientists from across the world have been nominated as WCRP Regional Focal Points. The WCRP Climate Research Forums are being held on a regional basis, but everyone is welcome to attend. You can register your interest to attend through the WCRP webpage.

The implementation of the new WCRP structure already begins now, with a 2-year timeline to transition from where we are in early 2021. By June 2021 we envision that the new WCRP will be in place. After that, the WCRP Grand Challenges and associated activities wil sunset and we will refine and improve the new WCRP, and envision that it will be fully operational by late 2022.

NOTE: The Implementation Plan is not a set and forget document; rather it is a living plan that will be written over the next 1-2 years, and continuously updated.

Find more information and documents on the WCRP webpage, or directly connect to WCRP, if you want to be involved.

Personal reflections on the outlook for SPARC

The COVID-19 pandemic is overwhelming the scientific community across the world. Climate science is not an exception. Most conferences and workshops, including AOGS, AGU, and EGU, were cancelled or switched into virtual meetings in 2020. Although virtual meetings boost diversity, they constrain developing relationships and holding informal discussions is much more difficult.

In the middle of this pandemic, SPARC and WCRP have been making significant progress in developing their new plans. Here, we try to step back and put these important developments into perspective, highlighting what progress should occur before the next WCRP JSC meeting (end of June 2021) at which the plans and how to transition to them will be agreed. As always, we welcome comments from the wider community - the success of the plans relies on the motivation and active involvement of individual scientists working together on topics where global cooperation is needed.

A new Implementation Plan for SPARC is needed as the last one ended in December! Its preparation has been deliberately delayed so that it can be developed in parallel with the emerging WCRP plans. The Task Team (see article on page 2) was set up involving scientists from all parts of SPARC. The co-chairs have been only peripherally involved in order to make it a true community plan reflecting the future research interests of SPARC scientists. It has affirmed the core themes for SPARC (atmospheric dynamics and predictability, chemistry and climate, and long-term records for climate understanding), the move to a whole atmosphere approach, and SPARC's dual role in promoting research on ozone depletion and on climate change. The Task Team is carefully reviewing what research should be strengthened in SPARC, what structure is appropriate to play a full role in WCRP, and even whether SPARC's name should change. The new plan will be presented to the WCRP JSC at its meeting at the end of June 2021.

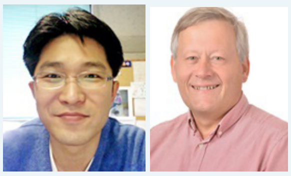
The state of planning in WCRP, discussed at an extraordinary session of the WCRP JSC in December 2020, is summarised on page 5. Briefly, the four core projects will become communities and be joined by ones on Earth Systems Modelling and Observational Capabilities and Regional Climate Information for Societies. High level ideas will be developed in the Lighthouses which will rely on the scientific underpinnings from the new communities. This structure gives many opportunities for SPARC scientists to pursue their research interests including, it is hoped, the increasing number of multi-disciplinary issues that are central to adapting to and mitigating climate change. The ideas for these are still being fleshed out and SPARC scientists are involved in all Lighthouses as well as in the regional forums which will provide a regional perspective on the plans.

SPARC sciences are critical to the proposed Lighthouses, and we see the discussion about the Lighthouses as an excellent way for SPARC to contribute to the WCRP science. There are opportunities to work more closely with the other WCRP homes, possibly as joint ventures or as one-off events. SPARC capacity building should be integrated with the WCRP academy and the regional climate fora to provide more opportunities for ECRs to be more closely engaged with WCRP and SPARC.

In the coming months the SPARC task team will develop a more concrete plan for our own activities, clarify the two-way interactions with the Lighthouses, and start identifying possible joint activities with other WCRP groups. In particular, SPARC needs to establish a clear relationship with the two new homes as their plans develop. Until the data-model home is set, SPARC may need to build and manage its own data depository for data produced by activities.

All these issues will be further discussed by the Task Team as they and the SPARC Steering Group translate scientific ideas into a plan which integrates into a broader WCRP. Many uncertainties remain. These will be ironed out in the coming months and in the transition from the current to the new WCRP structure. We welcome any suggestions, comments and offers of help.

Finally, we would like to draw your attention to the upcoming SPARC general assembly. The WCRP JSC have set a target of a 50% reduction in carbon footprint. SPARC need to come up with a strategy to achieve this goal for the general assembly and other SPARC activities. A suggestion for holding a multi-centre conference is being considered (see page 8) to maximise the climate advantages of an online meeting while minimising its disadvantages. All views will be welcomed.



Seok-Woo Son and Neil Harris, SPARC co-chairs

Prof. Dr. Hella Garny receives the 2020 International Prize for Model Development from WCRP/WWRP

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Winner of the WCRP/WWRP International Prize for Model Development, Hella Garny, DLR, Germany, and LMU, Germany.

We would like to congratulate Prof. Dr. Hella Garny from Deutsches Zentrum für Luft- und Raumfahrt (DLR) and Ludwig-Maximilians-Universität in Munich (Germany) for receiving the 2020 International Prize for Model Development from WCRP/WWRP!

Hella has always been excited about developing hierarchical modeling tools to study fundamental atmospheric processes at the interface of atmospheric dynamics and chemistry. She successfully completed this project with the development of the ECHAM/MESSy idealized (EMIL) model (Garny *et al.*, 2020), which is now employed for a wide range of applications. In addition to the development of this model, Hella has made significant contributions to the model evaluation and development of a range of other models and model processes. In particular, she advanced the possibilities to analyze the role of mixing for tracer transport and age of air in models by deploying a conceptual model framework (Garny *et al.*, 2014). Using this methodology, Hella and her group made important contributions to the coordinated model evaluation within the Chemistry-Climate Model Intercomparison (CCMI) Project (Dietmüller *et al.*, 2018).

Simplified and hierarchical model development constitute an often overlooked part of model development. These model hierarchies are crucial for a fundamental understanding of the climate system as they allow for the step-wise inclusion of the ingredients that are believed to be relevant for the simulation of a phenomenon or a complex process, facilitating a fundamental understanding of complex processes and connections in the climate system. An overview of model hierarchy research is described in Maher *et al.* (2019), who cite Hella's work (Garny *et al.*, 2014) as a crucial step towards interpreting changes in the stratospheric circulation.

Through her contributions in hierarchical model development and use, Hella has led the way towards a better understanding of stratospheric mixing, including subgrid scale mixing such as numerical diffusion, which is crucial for improving tracer transport in models. The EMIL model allows for simulations with a full transport and tracer scheme in an idealized setting, thereby allowing for testing of the transport scheme and process studies that advance our understanding of transport processes. This development is crucial in the simulation of projected changes in the stratosphere with climate change, including a strengthening of the circulation, which can significantly affect surface climate. The new model version developed in Garny *et al.* (2020) allows for the inclusion of chemical tracers in a dry dynamical core model to study the impact of idealized dynamical variability and changes on the distribution of chemical tracers.

In summary, Hella has made outstanding contributions to model development and plays a crucial role in the advancement of hierarchical modelling, improving our understanding of the interaction between chemistry and dynamics in the atmosphere, and the role of these interactions for a changing climate. Her work leads to a significantly improved understanding of the atmosphere in a changing climate.

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A new model for the SPARC General Assembly

Andrew Charlton-Perez[1], Elena Saggioro[1], Daniela Domeisen[2], Roland Eichinger[3], Neil Harris[4], Mareike Heckl[3,5], Manoj Joshi[6], Sanjay Kumar Mehta[7], Seok-Woo Son[8], and Don Wuebbles[9]

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The case for a different approach

The SPARC General Assembly (GA) is the largest meeting held by WCRP SPARC and brings together the whole SPARC community approximately every four years. There have been six SPARC GAs since 1996, held on all six continents. The most recent SPARC GA, held in Kyoto during early-October 2018, attracted a record 382 attendees despite disruption from Typhoon Trami. As preparations for the next SPARC GA in 2022 or 2023 begin, now is a good time to consider what shape the next GA might take and how we might reduce its environmental impact especially due to travel (Glausiusz, 2021).

It is hard to deny that scientific conferences have a large carbon footprint, as articulated clearly by Klöwer *et al.* (2020) for the annual American Geophysical Union meeting in San Francisco. This large meeting is estimated to generate around 80,000 tonnes of CO_2 equivalent (tCO_2e) or on average 3 tCO_2e per attendee for travel alone (not accounting for additional carbon and environmental impact generated by accommodation, food and materials). Undoubtedly, the ability for scientists to meet face-to-face does have significant benefits. Often informal discussion during coffee breaks, in poster halls, and over dinner can give valuable scientific feedback and lead to new and fruitful collaboration. Over the course of a scientific career, the network of collaborators built through conference attendance is enormously valuable. However, because of their high carbon and financial cost, it is becoming increasingly difficult to justify returning to the same scientific conference model that existed prior to the COVID-19 pandemic.

The scale and breadth of academic activities that happened virtually in 2020 was unimaginable only ten months ago. As many more people have attended fully online conferences, the previously underestimated benefits of virtual conferencing have become clearer. Many scientists with caring responsibilities can be excluded from international meetings where long-haul travel and extended periods away from home are necessary. Similarly, scientists in lower income countries are often unable to travel to present their work even when financial support is offered by SPARC. A fully or partially online conference model can help both by reducing these financial and social costs. Our ongoing collective experience of scientific collaboration during the pandemic is reshaping ideas on what conferences can and should look like. This new perspective may enable us to 'build conferences back better', reducing the long-term harm to our environment while benefiting more and diverse groups of people. At the recent DynVar/SNAP meeting in Madrid, a group of attendees including a large number of Early Career Researchers discussed the carbon impact of SPARC meetings resulting in an article in a recent newsletter (Saggorio *et al.*, 2020). Both this article, and Klöwer *et al.* (2020) and others suggest multi-hub conferences as an approach to reducing the need for long-haul travel while also retaining face-to-face interaction, a compromise between a traditional single site conference and a fully online meeting like those most of us attended in 2020. In this article, we propose a model for a multi-hub SPARC GA that could be delivered in 2022 or 2023. We encourage the SPARC community to:

- Comment on the proposal and its feasibility, pointing out alternative approaches that may improve it.
- Complete the accompanying survey to provide us with a basis for planning the GA: http://bit.ly/2MJFxSb (forms.office.com).
- Contact us if they are interested in being part of the organising committee for multi-hub GA, we particularly encourage participation from Early Career Researchers or anyone keen to develop alternative models of scientific collaboration.
- Contact us if their organisation might be able to offer to act as one of the continental hubs.

Some of the activities and groups in SPARC have already started thinking about the best approach for their own future meetings. SSiRC surveyed their community in mid-2020 and found a smaller preference for in person meetings than might have been expected, only 28% of those surveyed expressed a moderate or strong preference for in person meetings, with the majority of the 68 respondents having a preference for a mixture of in person and online meetings.

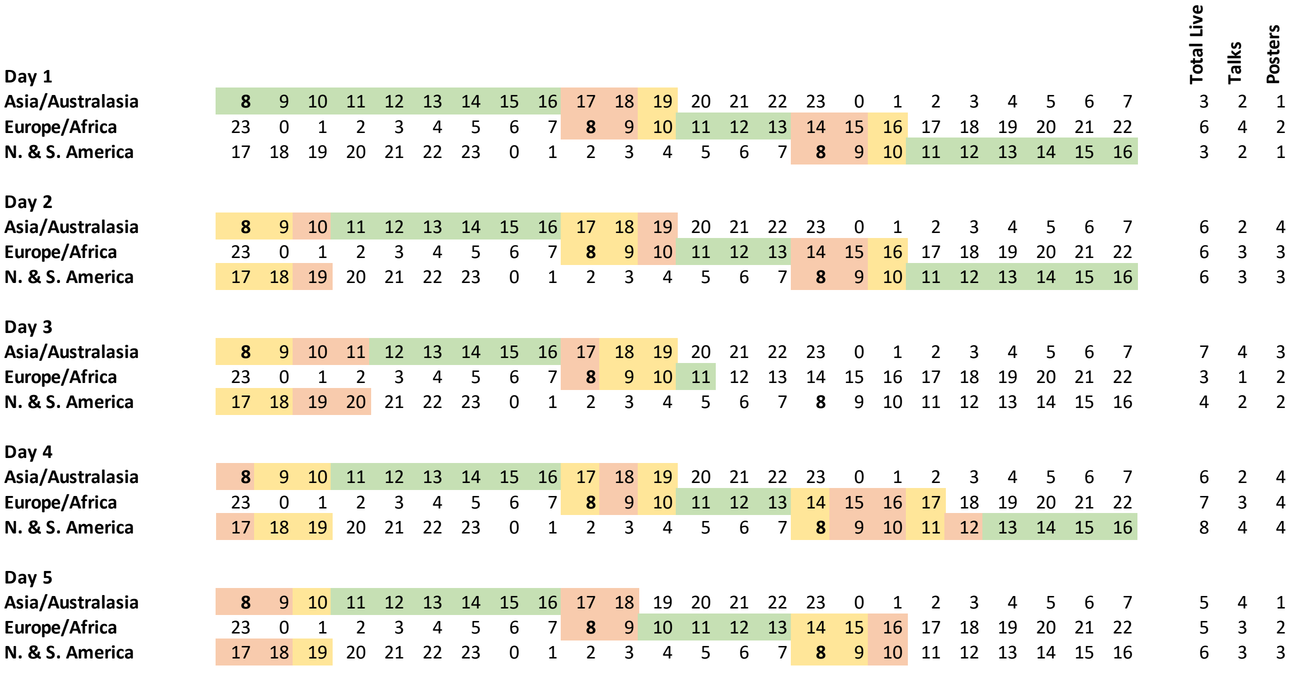
A multi-hub proposal

A number of other fields have adopted multi-hub approaches to large international meetings, and there is a growing movement designed to reduce academic flying in climate science (https://noflyclimatesci.org). In preparing this proposal, we have drawn particularly on the description of the ICMPC15/ESCOM10 conference described by Renee Timmers in this talk: https://www.carbonneutraluniversity.org/reducing-academic-flying.html. This conference had 4 international hubs and around 600 attendees and so is of comparable size to the SPARC GA.

One alternative to a multi-hub meeting is a fully online GA, but in our discussions we felt that this would lose the very important elements of face-to-face interaction discussed above. Nonetheless, because of its nature, a multi-hub GA would build in online participation and content recording as standard.

Based on the structure of time-zones and distribution of major population centres, a multi-hub conference with hubs located in each of the six main continents would be feasible. These hubs would naturally form three groups with parallel content in Asia and Australasia, in Europe and Africa and in North and South America. To reduce complexity, at least in the first iteration, it may be sensible to have fewer regional hubs that still reduce the need for significant travel for many participants. It might also be possible to provide incentives for greener travel options like train travel for some locations.

A proposed schedule for a five day meeting with any combination of between three and six hubs is shown below. The main difference to a standard, single location GA is that conference content runs over a longer conference day. In most cases, 'live' content is delivered simultaneously to two of the three groups of conference hubs.



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Day 1																											
Asia/Australasia	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	3	2	1
Europe/Africa	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	6	4	2
N. & S. America	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	3	2	1
Day 2																											
Asia/Australasia	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	6	2	4
Europe/Africa	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	6	3	3
N. & S. America	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	6	3	3
Day 3																											
Asia/Australasia	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	7	4	3
Europe/Africa	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	3	1	2
N. & S. America	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	4	2	2
Day 4																											
Asia/Australasia	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	6	2	4
Europe/Africa	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	7	3	4
N. & S. America	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	8	4	4
Day 5																											
Asia/Australasia	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	5	4	1
Europe/Africa	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	5	3	2
N. & S. America	17	18	19	20	21	22	23	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	6	3	3

🟥	Live Talks
🟨	Live posters
🟩	No content

Total	Talks	Posters	ALL
Asia/Australasia	14	13	27
Europe/Africa	14	13	27
N. & S. America	14	13	27

Figure 2: *Illustration of a possible multi-hub plan for the SPARC GA. Each block indicates 1 hour of conference time i.e. starting at the specified local time. Red blocks indicate oral sessions and where these span multiple hubs would be live, broadcast with talks taking place in any of the hubs. Yellow blocks indicate live poster sessions. Green blocks indicate no scheduled activity, but that the conference hub remains open for informal discussion, poster viewing and side meetings. In all hubs, there are 27 hours of scheduled conference time, allowing for free time in all hubs in common with SPARC GA tradition. No hub has scheduled sessions beginning before 8am or ending after 9pm.*

This content includes both plenary talks and posters. Remote delivery of posters would involve both real-time delivery at the hub where the presenter is located and a recorded summary of the poster at other locations. Questions/discussion for both posters and for plenary talks would occur both in real-time at each hub and asynchronously using chat tools like Slack or Discord. The longer conference day also means that at most hubs there are periods of no content delivery that can be used for catching up on recorded content from other hubs including talks, for networking and for spin-off meetings. Our intention would be that, if space allows, posters would remain on display during this period to allow large amounts of time for in-person discussion.

An indication of the structure of the meeting (for approximate time-zones given the location of the hubs is not yet known) is shown in Figure 2.

Without having detailed information about who might attend such a meeting, it is difficult to anticipate the precise carbon saving, beyond the fact that fewer longer-haul flights would likely mean a significant net carbon saving. As an indicator of the size of the reduction Klöwer *et al.* (2020) suggest that a three-hub model for the AGU meeting would result in an 80 % reduction in carbon footprint. As a lower bound, a fully online conference such as the European Astronomical Society meeting in 2020 estimated a total carbon footprint of 582 kg of CO_2 equivalent - roughly the emissions of a single return trip by airplane from Liverpool to Lyon- and about 3,000 times smaller than the face-to-face one in 2019 (Burtscher *et al.*, 2020).

Summary and Feedback

In this short article, we present a proposal for a multi-hub SPARC GA that addresses some of the concerns around the carbon footprint of our meetings. Although we present here a plan for a meeting with between three and six hubs, the plan essentially calls for three synchronized meetings that cover time zones in different parts of the world.

This proposal is meant to provoke discussion about the kind of meeting that the SPARC community hopes the next GA would be. A multi-hub conference as described is designed to combine the positive elements of a fully online meeting and a traditional single location face-to-face meeting, but we recognise that this remains a substantial logistical challenge. There are, of course, risks to this approach including reduced scientific benefit of the GA and major technical failure. The second of these risks could be mitigated by hosting the meeting at hub locations with significant prior experience of similar meetings. We feel that there is an exciting opportunity for SPARC to lead the way in building a large meeting structure suitable for science in the 21st century.

As noted in the introduction, we hope to hear from members of our community to give feedback on the proposed plan and welcome those keen to participate in the small group planning the GA.

Please complete the short online survey here:
http://bit.ly/2MJFxSb (forms.office.com)

On the survey page you will be able to provide detailed feedback in addition to providing some indication of your willingness to attend different types of SPARC GA. This will help us to produce a detailed plan that suits the need of the community.

Anyone who is interested in being part of the GA planning group or could offer space at their institutions as a potential conference hub, please contact Andrew Charlton-Perez.

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Current state of atmospheric temperature trends from observations

Milestone achieved by the Atmospheric Temperature Changes and their Drivers (ATC) Activity

Andrea K. Steiner[1]

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The SPARC Activity on Atmospheric Temperature Changes and their Drivers (ATC) focuses on gaining a better insight into atmospheric temperature variability and trends and on improving knowledge on the drivers of atmospheric climate change. Our aim is to contribute to the fundamental understanding of the climate system and its changes over time. Over the past years, the ATC activity has made substantial contributions to assessments of stratospheric temperature trends, based on observations and model simulations with regular contributions to ozone assessments (Ramaswamy *et al.,* 2001; Shine *et al.,* 2003; Randel *et al.,* 2009; Thompson *et al.,* 2012; Seidel *et al.,* 2016; Maycock *et al.,* 2018).

Recently, we have reached another major milestone of our ATC implementation plan with the publication of our community paper on atmospheric temperature changes from observations (Steiner *et al.,* 2020a), supported by SPARC/WCRP. The publication presents the current state of temperature trends in the troposphere and stratosphere from latest observational records for 1979 - 2018, with more than 40 years of meteorological satellite observations and novel observations from Global Navigation Satellite System (GNSS) radio occultation (RO) at hand.

Extensive efforts and reprocessing activities by members of the ATC activity over the recent years have led to substantial improvements and the reduction of long-standing discrepancies among observational data sets. Several data records have been produced by merging satellite measurements of the Stratospheric Sounding Units (SSU), the operational Advanced/Microwave Sounding Units (A/MSU) as well as new limb sounders, which provide continuous climate records of layer-average temperatures from 1979 to present.

The advent of GNSS RO observations in 2001 has led to further improved information on vertically resolved temperatures, enabling a detailed analysis of the upper troposphere and lower stratosphere (Scherllin-Pirscher *et al.,* 2020). RO data from multi-satellites and different processing centers were found highly consistent up to ~25 km, with a structural uncertainty in temperature trends of <0.05 K per decade in the global mean and <0.1 K per decade at all latitudes. The uncertainty above 25 km is increased in the early RO-period until 2006, while data from later missions – based on advanced receivers – are usable to higher altitudes for climate trend studies (Steiner *et al.,* 2020b).

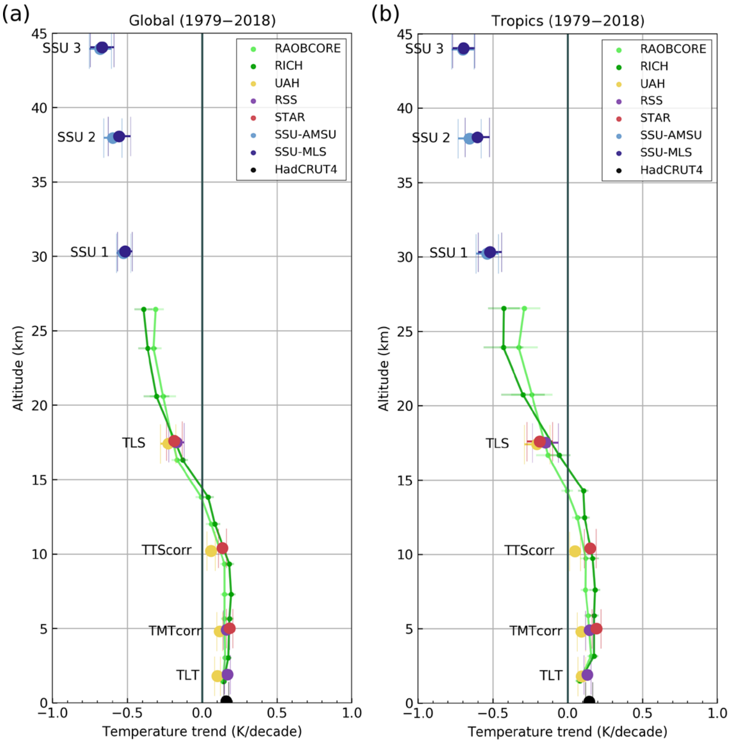

Figure 3: *Upper-air temperature trends 1979 - 2018 from different observations for (a) near-global averages (70 °S - 0 °N) and for (b) the tropics (20 °S - 20 °N). Layer-average temperature trends are shown for MSU-AMSU and for merged SSU records. Vertically resolved trends are shown for radiosonde records. Surface temperature trends from HadCRUT4 are also indicated. Trends were computed with multiple linear regression. Uncertainty of trends is indicated at the 95 % confidence level (Steiner et al., 2020a; Figure 8 therein; © American Meteorological Society. Used with permission.).*

Furthermore, we included vertically-resolved temperature records from ground-based observations, specifically from radiosondes and lidar measurements. Lidar data from four long-term stations showed good correlation with SSU time series. However, some remaining biases in some lidar time series are under investigation by the data providers. The radiosonde records were comprised of homogenized gridded products for 1979 - 2018 and also a time series of selected high-quality Vaisala radiosonde measurements from 1995 onwards.

The assessment of trends from atmospheric observations revealed a robust cooling of the stratosphere of about 1 K to 3 K over the last four decades with the magnitude of the trend increasing with height (Figure 3). Cooling was found larger in the first half of the record and was interrupted by volcanically induced stratospheric warming signals. Since the late 1990s, cooling trends of the lower stratosphere became weaker, which is regarded due to the recovery of the ozone layer. The latitude structure of trends shows cooling over all latitudes amounting to about −0.25 K per decade in the lower stratosphere up to −0.5 K to −0.7 K per decade in the middle to upper stratosphere.

In the troposphere, a robust warming of about 0.6 K to 0.8 K over the period 1979 - 2018 was observed (Figure 3). Significant warming was found over all latitudes from the lower to the mid-troposphere. Exception are the Southern high latitudes with near-zero trends while at Northern high latitudes the warming reaches about 0.3 - 0.5 K per decade. Since the 2000s, significant warming of the troposphere of 0.25 - 0.35 K per decade is evident in the RO records, consistent with gridded radiosonde records (Figure 4).

Furthermore, observations from RO and high-quality radiosonde data for 2002 - 2018 showed an amplification of temperature trends in the tropical upper troposphere compared to the surface, which is in approximate agreement with moist adiabatic lapse rate theory.

Overall, consistency was found in observed trends over 1979 - 2018 obtained from the latest observational records for satellite-based layer average temperatures and vertically resolved radiosonde records as well as for recent trends over 2002 - 2018 from GPS RO and radiosondes. The presented results are a contribution to the IPCC Sixth Assessment Report of Working Group I in Chapter 2 on the changing state of the climate system.

A further major highlight was the joint publication on heat stored in the Earth system (von Schuckmann *et al.*, 2020), a concerted international effort between the WCRP core projects CLIVAR, GEWEX, CliC, and SPARC and supported by GCOS. The publication presents an updated assessment of ocean warming estimates as well as new and updated estimates of heat gain in the atmosphere, cryosphere and land over the period 1960 - 2018 from observations and reanalyses.

Results show a total Earth system heat gain of 358 ± 37 ZJ over the period 1971 - 2018, which is equivalent to a global heating rate of 0.47 ± 0.1 Wm^{-2}. Over 1971 - 2018 (2010 - 2018), the heat gain amounts to 89 % (90 %) for the global ocean and to 6 % (5 %) over land; 4 % (3 %) heat is available for the melting of grounded and floating ice, and 1 % (2 %) for warming of the atmosphere (see Figure 5 on the next page).

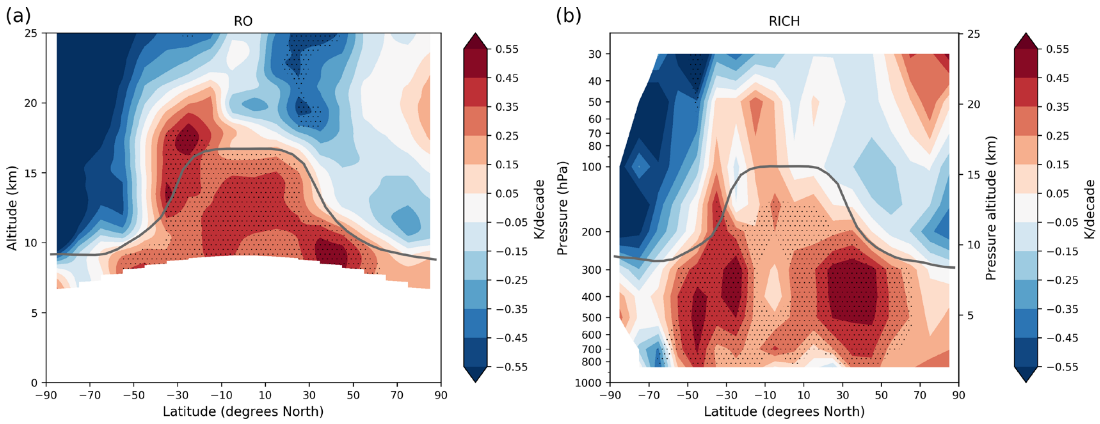

Figure 4: *Altitude versus latitude resolved trends 2002 - 2018 shown for (a) RO and (b) radiosondes. Trends were computed with multiple regression analysis. Trend values that are significant at the 95 % confidence level are indicated with dots (Steiner et al. 2020a; Figure 12 therein; © American Meteorological Society. Used with permission.).*

Atmospheric energy (denoted as atmospheric heat content) trends have clearly intensified. While the earlier decades of 1980-2010 show trends of near 1.8 TW, trends over 1993-2018 are about 2.5 times higher (4.5 TW), and even 3 times higher in the most recent two decades over 2002-2018, a period that is covered also by the RO and radiosonde observations.

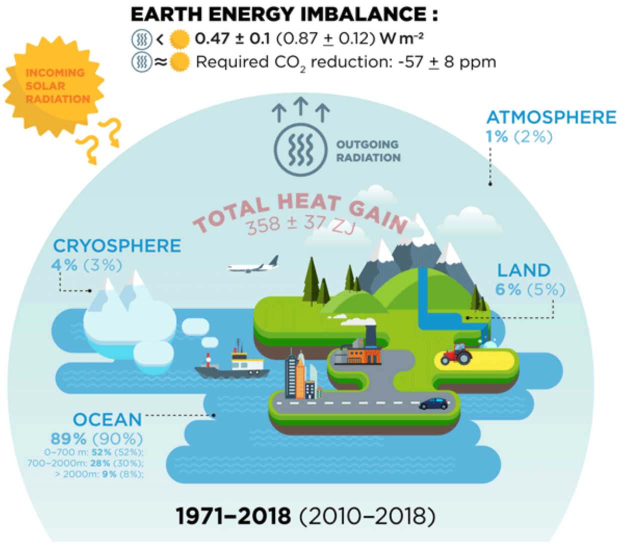

Figure 5: *Schematic presentation on the Earth heat inventory for the current anthropogenically driven positive Earth energy imbalance at the top of the atmosphere. The relative partition (in %) for the different components is given for the ocean, land, cryosphere and atmosphere, for the periods 1971-2018 and 2010-2018 (for the latter period values are provided in parentheses), as well as for the Earth energy imbalance (von Schuckmann et al. 2020; Figure 8 therein; CC BY 4.0).*

The findings improve our understanding of atmospheric temperature trends and underpin that consistent and long-term stable observations are critically important for monitoring the Earth's changing climate. The substantial expertise within the ATC activity on temperature retrievals, datasets and uncertainties is vital for producing and interpreting climate data records. These records are key to characterize how the climate system is changing over time.

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Over the past year many other SPARC activities have worked on and published or submitted community papers, including a review on Polar Stratospheric Clouds, new insights in the QBO, as well as a review of the current knowledge on the most important aspects of Sudden Stratospheric Warmings. Summaries of those works will be included in the next issue of the SPARC newsletter to be published in July 2021.

New Availability of High Vertical-Resolution Radiosonde Data for Research

Marvin A. Geller[1], Peter T. Love[2], Bruce Ingleby[3], and Xungang Yin[4,5]

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One of the principal goals of the FISAPS (FIne-Scale Atmospheric Processes and Structures) activity of SPARC "is to realize the full potential of large volumes of HVRRD (High Vertical-Resolution Radiosonde Data) archived worldwide, as well as other high-resolution data." These efforts date back to the early days of SPARC. Hamilton and Vincent (1995) stated the following: "SPARC adopted a resolution strongly encouraging the world's various national meteorological services to begin to archive operational radiosonde data at the highest available resolution." They noted that in 1991 the Australian Bureau of Meteorology began archiving their temperature soundings at 10 s (~50 m) at 36 stations that they operated. Hamilton and Vincent (1995) also noted that, starting in 1991, the United Kingdom Meteorological Office (UK Met Office) began archiving 2 s data at 12 stations that they operated, France began archiving HVRRD in 1994, and in 1995 the US National Weather Service began archiving 6 s HVRRD at 95 stations they operated. It has not always been easy for researchers to obtain those data, however.

Access to the US 6s-HVRRD was facilitated by a National Science Foundation grant that enabled purchase of the US data and by a NASA grant that allowed establishment and operation of the SPARC Data Center. At that point, the US HVRRD was archived in the SPARC Data Center and was freely available to all. Many papers, using these data, followed on gravity waves (*e.g.*, Wang and Geller, 2003), tropopause structure (*e.g.*, Birner, 2006), depth of the mixed layer (Seidel *et al.*, 2013), among other topics. In 2005, the US started transitioning to a new generation of radiosonde instrumentation that allowed 1 s data to be obtained. These data up to 2011 can be accessed through the SPARC Data Center, and after that can be obtained from NOAA NCEI (National Centers for Environmental Information, previously NCDC). Ko *et al.* (2019) utilized this data set to determine turbulence characteristics over the continental United States by Thorpe analysis (Thorpe, 1977, and Clayson and Kantha, 2008). Given the relative ease of access to the US HVRRD, Chinese researchers were using this data set to study gravity waves over the US (*e.g.*, Zhang *et al.*, 2010), and German researchers were using this data set to study tropopause structure over the US (*e.g.*, Birner, 2006). In the next section, we describe increased availability of global HVRRD. This increased availability makes it possible for researchers all over the world to carry out global HVRRD studies and also to perform detailed analysis of HVRRD from their own country and region.

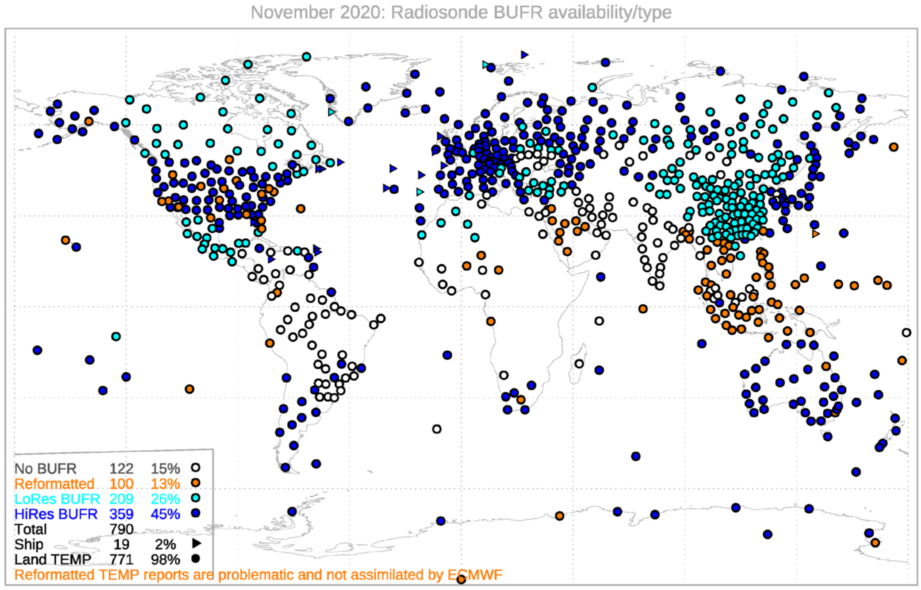

Figure 6: *Map of radiosonde stations reporting in November 2020 as processed at ECMWF, dark blue symbols show stations providing HVRRD; cyan symbols show those reporting low- resolution BUFR (Binary Universal Form for the Representation of Meteorological Data) .*

Migration from TEMP to BUFR

Ingleby *et al.* (2016) described the migration of radiosonde data from TEMP (the traditional alphanumeric code for radiosonde reports of temperature, humidity, wind, and height consisting of data at mandatory and significant levels) to BUFR (Binary Universal Form for the Representation of Meteorological Data) formats. BUFR can store the entire radiosonde ascent rather than just data at selected levels, and some countries provide HVRRD. Ingleby et al. (2016) showed that for the month of December 2015, 11 % of global radiosonde stations (77) that were decoded at the European Centre for Medium-Range Weather Forecasts (ECMWF) were reporting 3,000 or more data points in radiosonde soundings (see figure 4 of Ingleby *et al.*, 2016). That situation has now evolved to where Figure 6 shows that, as of November 2020, 45 % of global radiosonde stations (359) were reporting HVRRD.

While increasing HVRRD has been available to operational weather forecasting organizations, it is only recently that such archived data are becoming available to the research community.

Research Access to Increased Global HVRRD

To make the BUFR data available to the research community, Bruce Ingleby of ECMWF has been supplying those data to NCEI and to the Copernicus Data Hub, but there have been various hinderences to data access from those sites, so as of now, an interim arrangement has been made. Xungang Yin of NCEI has made those data available at https://www.ncei.noaa.gov/pub/data/igra/v1/related/BUFR/ecmwf/data/, and ECMWF has made the following BUFR decoding program available https://confluence.ecmwf.int/display/ECC/ecCodes+Home. (These files include different versions of the same ascent and LoRes as well as HiRes. Also, these data have been processed for operational purposes, and the highest resolution soundings have been "thinned," *i.e.*, the number of levels have been reduced).

Dr. Yin will be updating the monthly data files each month until a more permanent solution is implemented.

FISAPS Plans

To encourage use of these newly available global HVRRD, FISAPS intends to hold an international workshop in Boulder, Colorado, USA at some time to be announced in 2022 (Covid-19 permitting) where researchers around the world will be encouraged to present research using those data. We will be attempting to organize a peer reviewed special journal issue containing research papers from this workshop. In order to properly organize this workshop, please contact Marvin A. Geller at Marvin.Geller@sunysb.edu about your planned presentation at this workshop, and you will be kept informed about ongoing workshop plans.

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Lauder and its Part in the Ozone Success Story

Richard McKenzie

NIWA, Lauder, New Zealand.

Although completely unknown to most New Zealanders, Lauder is a world-famous research laboratory to the atmospheric science community. It's located on rolling farmland in the sparsely populated backblocks of Central Otago, on the South Island of New Zealand.

At latitude 45.04 °S (longitude 169.68 °E, altitude 370 m), it's almost exactly halfway between the equator and the south pole, in a data-sparse region of the globe. Surrounded by mountain ranges 1000-2000 m high, it's the nearest thing New Zealand has to a continental climate. It lies in a barren semi-desert landscape in a broad river valley, bounded by high country that casts an effective rainshadow. As a result, the annual rainfall is only 450 mm, with frequent clear skies and frosty winter nights.

The Beginnings

The Lauder laboratory began its life sixty years ago (in 1961) as an "Auroral Station". The location was chosen to take advantage of its clear night skies, its unobstructed views of the southern horizon, and the absence of pollution – particularly light pollution. At Lauder, the night sky can be impressively dark, with magnificent views of the Milky Way and even the Magellenic Clouds because there are so few man-made light sources visible: just a few farmhouse lights and occasional car lights from the tiny stretches of quiet roads that aren't obstructed by hills. The nearest town of any size is Alexandra, 40 km away. Its population then was less than 4000, now close to 6000.

The main tasks back then were measuring auroral activity from altitudes between 100 km and 400 km to better understand and quantify its effects on compass readings and the propagation of radio signals in those pre-satellite and pre-GPS days. They used radar systems to study radio aurora, and sensitive photometric systems to measure optical emissions from Aurora Australis, which is visible from land at only a few other locations outside the lower South Island of New Zealand. Changes in auroral activity (caused by changes in solar output) induce tiny variations in the electric currents that circulate in the ionosphere.

Figure 7: *View north from above the optics building at left foreground. The straight line extending north east from it is a gas line from a sampling tower. To its right is the dome that houses a steerable X-band antenna to receive satellite imagery. The main office block is at right centre, with staff housing among the trees to the left. To the right is the meteorological enclosure and the Dobson hut. In the background are the Dunstan Range and Mount St Bathans (2088 m), with the Hawkdun Range clearly visible up to 50 km away behind. Photo credit: Dave Allen, 2016.*

These in turn affect the strength and direction of the magnetic field and therefore compass readings that were a crucial navigational aid.

With the advent of satellite-borne instruments in the 1970s, Lauder's immediate future was assured by becoming a ground station for receiving ionospheric measurement data from a Canadian series of satellites (called ISIS). That's when the original wooden huts that constituted the lab were replaced by new (modern for the time) block buildings. But another Canadian was more influential in the long-term direction and success of Lauder. That was **A.W. (Tony) Harrison**, from the University of Calgary.

Stratospheric research at Lauder

In January 1979, a few months before my arrival at Lauder, he brought a spectrometer to measure nitrogen dioxide at twilight using a technique pioneered by John Noxon in the USA **[1]**. The technique didn't yet have a name, but would come to be called differential optical absorption spectroscopy (or DOAS). The wavelengths of solar radiation involved are near 430 nm and, because of the twilight scattering geometry for these zenith-viewing instruments, the method is most sensitive to gases in the stratosphere about 20 - 30 km above the Earth's surface – much lower than the ionosphere, but well above the troposphere. At the time, supersonic aircraft that would fly in the stratosphere were being developed, and there was concern about possible effects of their exhaust on the ozone layer because catalytic cycles involving the oxides of nitrogen were known to be capable of destroying ozone.

When I arrived at Lauder in November 1979, the long-term station manager, **Gordon Keys**, was on extended sabbatical leave in Germany, and **Paul Johnston** (later station manager in the 1980s and 2003 - 2012) was the stand-in during his absence. With interest starting to wane in upper atmospheric research, Paul and I decided to branch out and extend Harrison's work. That was the beginning of stratospheric research at Lauder. As fate would have it, that turned out to be an inspired change of direction.

By the time the Antarctic Ozone Hole was discovered in 1985, we had already applied the method to measure the annual variability of stratospheric ozone **[2]** and NO_2 **[3]** at Lauder: the latter showing that the column amounts are dominated by photochemistry. And corresponding measurements of tropospheric NO_2 **[4]** demonstrated the pristine characteristics of the air, with concentrations sometimes less than 100 ppt. We'd also begun making long-term twilight measurements of ozone and NO_2 in Antarctica. In fact, our Antarctic paper on the subject **[5]** was one of just seven cited in Farman's landmark paper **[6]** signalling the discovery of the Antarctic ozone hole. It was significant because, while Farman and others suspected CFCs were the culprit **[7]**, others thought the ozone decreases were attributable to high concentrations of NO_2 being modulated by solar activity. We showed that the concentrations there were similar to those at mid-latitudes, and we later went on to show that solar activity has only a minor effect on stratospheric NO_2 **[8]**. We were at the centre of an exciting new field. And the funding flowed, especially under the entrepeneurial management of **Andrew Matthews**, who was station manager from 1992 to 2003.

With the heightened interest in ozone and its effect on UV and human health, we went on to develop state-of-the-art UV spectrometer systems capable of detecting any changes in UV due to changes in ozone. We are still involved in the operation and maintenance of several of these at Lauder and at key locations in Australia and the USA.

Understanding the causes and effects of ozone change

In the decades that followed, the scope of measurements increased dramatically and Lauder became the prime southern hemisphere site for stratospheric research. With the help of other international groups, we began measuring a range of trace gases concerned with ozone depletion, as well as measuring ozone and its distribution with altitude using a plethora of different techniques.

Since the early 1990s, Lauder staff have had leadership roles in several of the WMO/UNEP Ozone Assessments that have pushed forward our understanding of ozone depletion and its consequences.

These include both the **Scientific Assessments of Ozone Depletion**, and Assessments of the Environmental Effects of Ozone Depletion (and their interactions with Climate Change). There has also been strong involvement with the **IPCC Reports on Climate Change** (but only one Nobel prize winner).

In the 1990s Lauder became the southern midlatitude charter site in the newly established Network for the Detection of Stratospheric Change (NDSC). The scope of the Network would later be broadened to include effects of climate change, and renamed to the Network for the Detection of Atmospheric Composition Change (**NDACC**). Our brief had become to "understand the causes and effects of ozone change".

We played a leading role in specifying the instrument characteristics required to detect long term trends in UV due to ozone depletion [9]. These were put to the test three decades later when UV spectrometers from the network were used to demonstrate the success of the Montreal Protocol in curbing increases in UV radiation [10]. To address health concerns about ozone depletion we'd much earlier demonstrated the inverse relationship between ozone and skin-damaging UV [11], charted the increases in peak UV as ozone declined in the 1990s [12], and showed the altitude dependence of UV [13]. We also showed how to deduce UV irradiances from global short wave irradiance data [14] and applied the method to derive **UV at multiple sites** throughout the country. One of our most quoted results (sometimes misquoted by sunscreen advertisers) was our finding that the peak UVI at Lauder is 40 percent larger than at corresponding northern latitudes [15] (but is still far below the global maximum [16]).

Our measurements in Antarctica showed that heterogeneous chemistry on background aerosols [17] is involved in the rapid denitrification of the Antarctic atmosphere in autumn (conversion of NO_2 to HNO_3), which is a prerequisite for efficient chlorine-catalysed ozone loss in the following spring [18], and that the rates of heterogeneous chemistry were more rapid in the presence of volcanic aerosol transported from the eruption of Mt Pinatubo in 1991 [19]. Our measurements at Lauder following that eruption also demonstrated large changes associated with heterogeneous chemistry on the aerosol surfaces [20] (though ozone itself was inexplicably unaffected by the aerosols over Lauder).

Figure 8: *Aerial view of the main office blocks in 2016, showing the newly installed array of solar panels that supply solar energy and are also used for research. Photo credit: Dave Allen, 2016.*

We showed that in New Zealand, the total amount of ozone in summer is less than at comparable northern latitudes, with the amount in the troposphere being only half that in the north [21]. Back trajectory analyses showed that about half of the mid-southern latitude stratospheric ozone decline in the latter part of the 20th century was from imported ozone-depleted air from Antarctica [22]. To resolve long term calibration issues with satellite derived ozone retrievals, we developed tools to generate global ozone fields referenced to the ground based network [23], so allowing accurate trend analyses from the satellite-derived products needed for ozone assessments.

With the eruption of Mount Pinatubo in 1991, Lauder's interest and expertise expanded to include the measurement of aerosols, with a range of instruments [24], and clouds [25], and their effects on ozone and UV [26]. The continuous aerosol lidar time series from Lauder now covers three decades, from the Pinatubo aftermath to recent eruptions [27]. The aerosol record also shows the intercontinental transport of seasonal biomass burning [28],[29]. By extension of the radiation measurement programme, Lauder joined the international Baseline Surface Radiation Network (**BSRN**). Measurements from that work demonstrate that Lauder routinely has some of the lowest aerosol optical depths [30] on Earth. As well as its importance for other Lauder measurements, this factor showed that global dimming and brightening [31] observed in NZ was not from aerosols as postulated elsewhere.

A new topic: climate change

That broadening of scope was serendipitous because as the ozone problem now recedes, the effects of climate change – and attempts to mitigate it using climate interventions involving aerosols - have come more into focus. In addition to measuring most of the gases relevant to ozone depletion, we also now measure the main gases involved in climate change. Several greenhouse gases are measured in situ at Lauder, and a large part of the current effort involves measurements of these gases from their absorption of solar infra-red radiation using Fourier transform spectrometers. Since 2004, data from the latter have contributed to a 3rd international network: the Total Carbon Column Observing Network (TCCON), which strives for a measurement accuracy of 0.2 %. Lauder is the southernmost site in the network, and with New Zealand's unique carbon footprint, where the warming effect from CH_4 and N_2O emissions are similar to that from CO_2, our measurements will have an important role to play.

Staff numbers at Lauder continued to grow through the 1980s and 1990s, a period that included a major reorganization of Science in New Zealand. Prior to 1992 Lauder was part of the Government's Department of Scientific and Industrial Research (DSIR), but after the reorganization, it fell under the umbrella of the newly formed National Institute of Water & Atmospheric Research (NIWA). NIWA was one of nine Crown Research Institutes that are owned by the government, but operate under their own management with an expectation that an annual dividend would be returned to the government. Around the turn of the century staff levels at times exceeded 20 (including post-grad students), boosted largely through **Greg Bodeker**'s scientific leadership.

Figure 9: *Night-time photograph showing the enclosure for the BOOTES telescope at front right, with the night sky featuring the Milky Way, one of the Magellanic Clouds to its left, and other stars (including the Southern Cross). Some auroral activity is visible above the southern horizon, with light spill to its left from the town of Alexandra 40 km away. Photo credit: Petr Horalek.*

For a time there was even an in-house modelling capability at Lauder. Highlights of their work included calculating global ozone fields in the World Avoided (by successful application of the Montreal Protocol) **[32]**, improved simulations of ozone recovery **[33]**, and assessing the impact of global warming from ozone-depleting substances **[34]**.

Recent changes at Lauder

There was a major funding crisis for Lauder in 2012, when its very existence came under threat. It escaped intact only after an international outcry but with a number of redundancies. By that time, our UV studies had moved away from pure atmospheric research more towards health effects of UV **[35]**, both positive **[36]** and negative **[37]**.

For the first few years that followed, Lauder was only a shadow of its former self, especially after its small team of atmospheric modellers relocated to Wellington to work alongside NIWA's new supercomputer. It's gradually starting to rebuild, but there are now only about 10 full time staff, and new avenues of funding are always being sought. It's now also a test site for materials degradation with the Building Research Organisation of New Zealand (BRANZ). And it has again become a ground station for satellite data – this time satellite imagery – taking advantage of its good horizon views, low noise at radio frequencies, and fast internet access. In recent years, Lauder has become a calibration centre for NIWA's New Zealand-wide network of radiation sensors. These measurements are highly relevant in the projected move from fossil fuels to renewable energy.

In 2015, Lauder became the first certified southern hemisphere site for yet another international network: the GCOS Reference Upper Air Network (GRUAN). The aim of GRUAN is to archive the highest quality vertical profiles of atmospheric temperature and relative humidity (and soon ozone) measured from balloon flights to validate satellite data and climate models.

But Lauder's most recent acquisition has been the most profoundly different – and it's not related to atmospheric research.

It's the deployment of a steerable 0.6 m diameter telescope designed to probe the histories of deep space to learn about the origins of our universe. It's called the **BOOTES** telescope – where BOOTES stands for the Burst Observer and Optical Transient Exploring System.

The current range of atmospheric measurements, summarized in the chart below, is quite staggering for such a small group. The ozone lidar, which has operated in partnership with **RIVM** (in the Netherlands) since 1994, is one of only 5 worldwide, and the only one in the southern hemisphere. Very recent data from the network showed systematic reductions in the age of air above Lauder over the last 25 years, which may have important implications for ozone recovery **[38]**. The full suites of measurements required by both the NDACC and the BSRN global networks are all measured at Lauder.

The global prognosis for our atmosphere looks grim. We appear to be careering towards an unchartered regime of future climate patterns. Although it's acknowledged that fossil fuel use must decline, there's been little slow down so far. But Lauder is well positioned for the future. It's the best instrumented site in the Southern Hemisphere- and arguably the world - for middle atmospheric research. Its pristine air and clear skies are added bonuses. We already have the capability of measuring any gas of aeronomic interest (and extending those back in time for decades). And most of the climate interventions being considered will have potential effects on many of the parameters already being measured at Lauder.

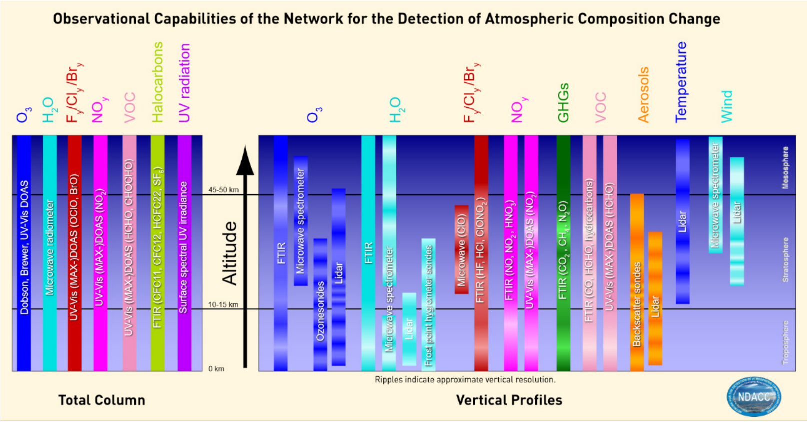

Figure 10: *Suite of NDACC Measurements. All are undertaken at Lauder. Credit:* ***NDACC***.

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The author's book "Saving our Skins", available (in three formats) from Amazon is a very personal account of his journey through research at Lauder over the last 40 years that has contributed to the success of the Montreal Protocol.

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