SPARC Activity Report 2019

Atmospheric Temperature Changes and their Drivers (ATC)

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I. Achievements and Plans

** What has your activity achieved over the past year?*
** Have you completed any major deliverables e.g. reports or reviews or reached any major milestones?*
** How do those achievement tie into the three main themes of SPARC?*
(This material will be incorporated into the Annual Report).

Achievements of the SPARC ATC activity tie into SPARC's main theme on *Long-term records for climate understanding* regarding the provision of updated and new observational records and analysis of atmospheric temperature trends and variability as well as into SPARC's main theme on *Chemistry and climate* regarding the understanding of drivers of climate change.

Conference organization, presentations, and contributions to the IPCC AR6

The ATC co-chairs have been invited to present work of the ATC activity at several conferences and workshops. Co-chair Andrea Steiner gave an invited talk at the American Geophysical Union Fall Meeting 2018 in Washington DC on atmospheric temperature trends from observations. She was Organizer and Co-chair of the session on "Klimawandel, Klimavariabilität, Auswirkungen auf die Gesellschaft" at the meteorological conference DACH 2019, Garmisch-Partenkirchen, Germany, March 2019. She presented also ATC activity work there. Co-chair Amanda Maycock will give an invited presentation at the 2020 AMS 100 Annual Meeting Middle Atmosphere Session on the role of the stratosphere in future climate.

In November 2018, Andrea Steiner acted as co-organizer of the WCRP workshop "The Earth's Energy Imbalance and its implications (EEI)", Toulouse, France, with main organizers from CLIVAR CONCEPT-HEAT and GEWEX. It brought together experts from different fields, ocean, atmosphere, cryosphere, and land. Outcome was a workshop report, a planned community paper, and a statement to the WCRP on continuation of joined work on the Earth's Energy Imbalance and its implications.

Co-Chair Andrea Steiner was invited as SPARC co-chair to join the ISSI Team, led by Alain Hauchecorne (LATMOS, CNRS, France) and ATC members Chantal Claud and Philippe Keckhut on synergy between satellite and ground-based observations for the study of middle atmosphere dynamics. The goal is to combine information from different observations, beneficial for a better representation of the middle atmosphere and for improving atmospheric models and numerical weather prediction. The first meeting was held in Bern, Switzerland, in March 2019, where Andrea Steiner presented the SPARC activity work. Joint publications are planned.

The RO community was invited to contribute data and graphics to chapter 2 on observations for the Working Group I of the IPCC Sixth Assessment Report (AR6). ATC activity member Florian Ladstädter and co-chair A. Steiner were involved in cooperative work for the IPCC contribution over the year and provided information on atmospheric trends from RO, radiosondes, and SSU/MSU records. A closed session on RO contributions for the IPCC

report, with the IPCC lead authors of chapter 2 attending, was held at the international workshop for atmospheric remote sensing by radio occultation, the ROM SAF-IROWG 2019, Elsinore, Denmark, September 2019. Andrea Steiner furthermore presented ATC activity work in the climate session. Co-chair Amanda Maycock is Lead Author of AR6 chapter 4 "Future global climate: scenario-based projections and near-term information"; ATC-member Nathan Gillett is Coordinating Lead Author for chapter 3 "Human influence on the climate system".

ATC-members Karen Rosenlof, Qiang Fu and Amanda Maycock were invited to join a new ISSI team "Tropical Width Impacts on the STratosphere", which will examine different measures of the stratospheric tropical pipe, including temperature information, and compare their past and future changes in observations and models. The team will meet for the first time in June 2020.

Presentations

Steiner, A. K., F. Ladstädter, and the SPARC ATC Activity, Atmospheric temperature trends from observations – an update, AGU Fall Meeting 2018, Washington, D.C., USA, December 2018 (invited).

Steiner, A. K. and the SPARC ATC Activity, SPARC Activity on Atmospheric Temperature Changes and their Drivers (ATC), ISSI Team Meeting on Middle Atmosphere Dynamics, Bern, Switzerland, March 2019 (invited).

Steiner, A. K., F. Ladstädter, H. Wilhelmsen, M. Stocker, and P. Peter, Klimavariabilität und Trends in der freien Atmosphäre aus Beobachtungsdaten, DACH 2019, Garmisch-Partenkirchen, Germany, March 2019.

Steiner, A. K., F. Ladstädter, and the SPARC ATC Activity, Atmospheric temperature trends from observations – an update on recent advances, EUMETSAT ROM SAF-IROWG 2019, Elsinore, Denmark September 2019.

Maycock, A. C. et al. The role of the stratosphere for future climate, AMS 100 Annual Meeting Middle Atmosphere Session, Boston, January 2020 (invited).

Papers and Milestones

The ATC community paper on an update on atmospheric temperature trends from observations is the second major milestone of our ATC implementation plan. Lead by Andrea Steiner, the paper provides an update on temperature trends in the troposphere and stratosphere from different observational records, on consistency and uncertainties in trends. It comprises information on layer-averaged temperatures from satellite SSU/MSU-merged records and vertically resolved temperatures from RO, radiosonde, and lidar observations. Recent advancements in observational data sets as well as limitations are discussed. Work is currently in its finalization and will be submitted by the end 2019 for contribution the IPCC AR6 WG I Chapter 2. (Steiner et al., in preparation for submission to J. Climate).

Furthermore, a joint publication on the Earth's heat inventory is currently in preparation as an outcome of the WCRP workshop on "The Earth's Energy Imbalance and its implications". Organized by WMO/GCOS, the paper is led by Karina von Schuckmann (Mercator Ocean International, Toulouse, France). Andrea Steiner leads the section on atmospheric energy storage change, co-authored by ATC member Leo Haimberger. The paper is aimed as a contribution to IPCC AR6 WG I Chapter 7 on Earth's energy budget. Submission is planned by the end of 2019.

In addition to the joint community activities, the ATC activity members have published several relevant papers this year on atmospheric data records and on the analysis of atmospheric variability and changes based on observational records and models. The 40th anniversary of

satellite temperature measurements was celebrated in a Nature Climate Change contribution by Santer et al. (2019a).

A new MesosphEO data set of temperature profiles from 35 to 85 km has become available using Rayleigh scattering at limb from GOMOS/ENVISAT daytime observations (Hauchecorne et al. 2019). In addition, a new version of the GOMOS dataset (HRTP FSP v1) has been processed with high-resolution temperature profiles retrieved from bichromatic stellar scintillation measurements by GOMOS/Envisat. The HRTPs are retrieved with a very good vertical resolution of ~200 m and high precision (random uncertainty) of ~1–3 K for altitudes of 15–32 km and with a global coverage. L. Haimberger (Univ. Vienna) has constructed newly homogenized radiosonde data. They are assimilated in the ERA5 reanalysis, which has become available in 2019 (Hersbach et al. 2019 in review).

Steiner et al. (2019) submitted an RO community paper, currently an AMT discussion paper, on the consistency and structural uncertainty of GPS radio occultation records from multiple missions. They found that structural uncertainty in trends is lowest from 8 km to 25 km altitude globally for all inspected RO variables and missions. For temperature, it is <0.05 K per decade in the global mean and <0.1 K per decade at all latitudes. Above 25 km, the uncertainty increases for CHAMP while data from the other missions are based on advanced receivers and are usable to higher altitudes for climate trend studies. Ho et al. (2019) published an overview on the accomplishments of RO observations from the COSMIC/FORMOSAT-3 mission. They discuss remaining challenges and potential impacts of the COSMIC-2 mission launched successfully in June 2019.

Stocker et al. (2019) quantified stratospheric temperature signals and climate imprints from post-2000 volcanic eruptions using vertically resolved aerosol data (GloSSAC) and temperature observations from radio occultation (RO). In the lower stratosphere, robust warming signals were observed, while in the mid-stratosphere cooling signals also appear for some eruptions (Figure 1). A volcanic contribution to the temperature trend was found to be up to 20%, depending on latitude and altitude. In a case study on the 2008 Kasatochi eruption, Cigala et al. (2019), used RO observations for detecting volcanic cloud top and for tracking of the cloud with synergistic satellite-based observations.

Santer et al. (2019b) compared externally forced change and internal variability in temperature trends from two climate model large ensembles. They showed an important role for both aerosol radiative forcing and the magnitude of warming due to greenhouse gases in the differences between the two models. They showed greatest consistency in fingerprint detection times with satellite data for the model with large aerosol cooling and large GHG warming. This highlights the importance of better constraining aerosol radiative forcing.

Randel and Park (2019) demonstrated that tropopause temperatures exert a dominant control over global stratospheric water vapour and the interannual variations. They used the relationship with observed tropopause temperatures to estimate water vapor changes over time, and these calculations showed excellent agreement with satellite measurements over the globe.

Richardson et al. (2019) quantified the surface temperature change efficacies for different climate perturbations in a set of climate models and showed that, when effective radiative forcing is used, the multi-model mean efficacies for aerosols, methane and solar forcing are close to one. This has implications for deriving ECS estimated from the historical surface temperature record.

Fu et al. (2019) provided observational evidence that overall the annual mean Brewer-Dobson circulation (BDC) has accelerated in the last 40 years (at the 90% confidence level) with a relative strengthening of ~1.7% per decade. Using MSU/AMSU lower-stratospheric

temperatures, they found that the BDC accelerated for 1980–1999 while it decelerated for 2000–2018, with changes largely driven by the Southern Hemisphere, partly due to the effects of ozone depletion and healing. Ozone-depleting substances (ODS) were found the main driver of the BDC over the last decades based on reanalyses and model simulations (Abalos et al. 2019). The effects of ozone depletion in the Antarctic lower stratosphere dominate the ODS impact on the BDC, while their direct radiative impact was negligible over the study period.

Chrysanthou et al. (2019) demonstrated the effect of nudging meteorological fields for modelling the Brewer Dobson circulation over the past 30 years. Nudging was shown to not constrain the mean strength of the residual circulation or modelled long-term trends, but it did constrain interannual variability associated with resolved planetary wave forcing. The study has implications for the use of nudged model simulations to study tracer transport and trends.

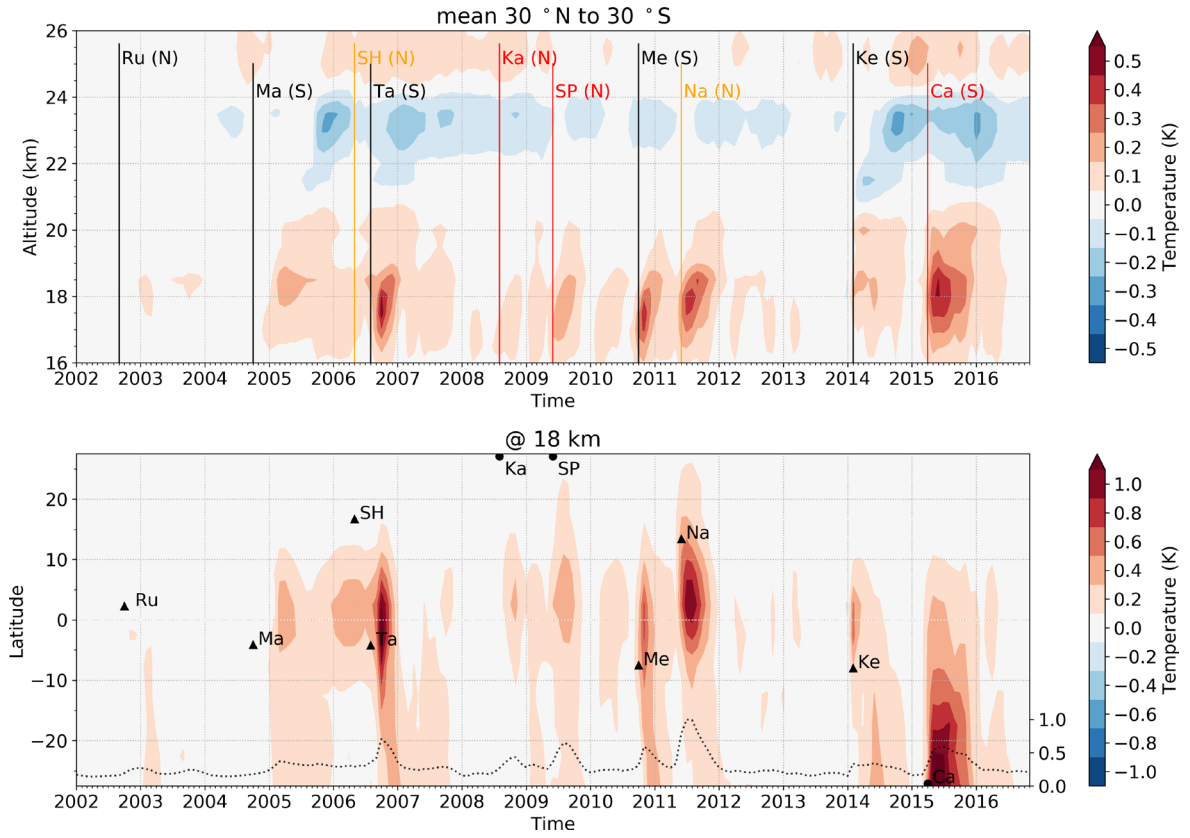

Figure 1: Altitude time cross section of the volcanic aerosol reconstructed temperature (mean 30°N to 30°S; top) as well as the latitude time cross section at 18 km (bottom). Vertical lines in the altitude time pattern mark the date of the eruptions. N and S in brackets indicate north and south of the equator. Line colors indicate the latitude of the eruption (red >30, orange >10, and black <10). Triangles in the latitude time pattern mark the date as well as the latitude of the eruption. Eruptions that occurred at latitudes not part of the plot range are marked with a semicircle. The dashed line represents the normalized VEC for the 18-km altitude level (mean 30°N to 30°S).

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* *What does your activity plan to do over the coming year?*
* *What deliverables (e.g. reports, review papers) do you plan to complete?*

(This material may also be incorporated into the Annual Report).

This ATC community paper on an update on atmospheric temperature trends from observations is the second major milestone of our ATC implementation plan and should be finally published in 2020.

All contributions of the ATC activity to the IPCC AR6 WG I will be revised and completed in 2020.

Contributions to papers of the ISSI Team "Synergy between satellite and ground-based observations for the study of middle atmosphere dynamics". A second ISSI Team meeting will be held in May 2020.

ATC-members Karen Rosenlof, Qiang Fu and Amanda Maycock are part of a new ISSI team project "Tropical Width Impacts on the STratosphere", which will meet for the first time in June 2020.

There is a plan with SOLARIS-HEPPA for a joint synthesis paper on solar cycle signals in stratospheric temperatures covering the latest satellite measurements, reanalyses and model simulations. This is in the early stages of discussions but will hopefully progress in 2020.

The ATC activity plans to join the 11th International Workshop on Long-Term Changes and Trends in the Atmosphere (TRENDS 2020) which will be held on 25-29 May, 2020, at the Finnish Meteorological Institute (FMI), Helsinki, Finland, and is jointly organized by SPARC LOTUS activity members and the SPARC ATC activity member Victoria Sofieva.

The CMIP6 dataset is now becoming available. A key emerging issue is that some CMIP6 models show a higher equilibrium climate sensitivity (ECS) than previous models, with around one third of models showing ECS>4.5 K. This increases the peak warming rates over the 21st century. This will be a major communication challenge for IPCC AR6 and the climate science community as a whole. Forster et al. (2019) have written a Comment for Nature Climate Change on how these high ECS models may be interpreted. One emerging topic for the ATC activity is whether the temperature trends in the CMIP6 models over the historical period can be reconciled with observations and/or whether observations could provide some constraints on the model behaviours. This is a topic where the ATC activity could usefully contribute and we will continue to develop discussions/plans in 2020.

Forster, P. M., A. C. Maycock, C. M. McKenna, C. J. Smith (2019) Latest climate models confirm need for urgent mitigation, Nature Climate Change, in press.

* *What is your vision for the new SPARC strategy?*
* *Which direction would you like to see SPARC move forward to?*
* *What are the main scientific questions that should be addressed in the next 5-10 years?*

Observations and climate data records

Supporting and lobbying for a coherent long-term monitoring system, i.e. the Global Climate Observing System (GCOS), including a framing of the integration of data from the private sector. Sustaining long-term climate data records (CDRs) of essential climate variables (ECVs). Improving the maturity of CDRs by further advancing retrievals and processing methods for providing consistent and homogeneous data sets with uncertainty information. Provision of benchmark records as a reference for observations and climate model simulations. Regular assessments of atmospheric ECVs, e.g., upper-air temperature by performing intercomparison studies of atmospheric observations.

Advancing science frontiers

Emphasis on fundamental science. Exploiting long-term climate data records for gaining fundamental understanding of short-term climate variability and long-term climate trends from

the troposphere to the mesosphere and their causes. How do long-term changes alter atmospheric weather patterns and trigger atmospheric extremes and surface impacts (Arctic amplification, atmospheric blocking, jet stream changes). The role of internal variability for regional climate trends is something that CLIVAR traditionally do, but the SPARC expertise in predictability and dynamics is also central to this.

Collaboration across core projects

Fostering cooperation across the WCRP between the observation, reanalysis, and modelling communities for improving climate data records and for tackling fundamental science questions.

SPARC's success has largely relied on self-organisation by the community in the form of bottom up activities. This model works because groups focus on the topics that are relevant to their individual research programmes; however, does this model position SPARC to be able to respond to key emerging issues? In many cases, yes. The time-limited activity on carbon tetrachloride is testament to this. But in other cases, the SPARC model may mean short-term gaps and opportunities are missed if the community is not ready to respond and mobilise (plus a potentially long process of becoming an emerging activity). How could we improve organisation-wise around identifying and mobilising groups to address key topics/issues?

Several of the Grand Challenges have been successful so far. However, they have been rather autonomous and separate from the core projects. What will supersede the GCs? It would be nice if the successors to the GCs were cross-cutting themes that bring together scientists from across the core projects. A pertinent example is the current cooperation across the WCRP areas on the Earth's energy imbalance, see statement submitted to the WCRP by von Schuckmann et al. on "Where does the heat go? – Earth's Energy Imbalance and its implications" for a WCRP concerted international effort to estimate EEI and its impacts, to assess gaps in the global climate observing system, and the performance of Earth system models and reanalyses of past data.

Meeting societal challenges

Emphasis for society on climate issues toward a sustainable future will either be on intense mitigation and its effects, and/or on geoengineering and effects. Monitoring and stocktaking is at the heart of this, with close monitoring of progress towards internationally agreed and binding climate targets. Governments will want to know whether the actions they are taking to achieve the UNFCCC Paris Agreement targets are working (cf. Montreal Protocol). This will be determined by a complex interplay between aerosol and greenhouse gas radiative forcing, internal variability, ECS and transient climate response, all of which are uncertain/unknown. Monitoring of the delivery, sustainability and effects of geoengineering technologies will be required, should they be deployed. New approaches to synthesizing and interpreting information (big data) in an operational system and data integration strategies will be required.

II. Resources

* *What workshops have you planned for the coming year and what level of WCRP/SPARC funding do you require to support those workshops?*
* *For what do you intend to use any allocated funding?*

(This information will guide the allocation of SPARC travel support over the coming year).

We would like to request some modest travel support to help members attend the joint 11th International Workshop on Long-Term Changes and Trends in the Atmosphere (TRENDS 2020), 25-29 May, 2020.

* *What funding proposals does your activity have in the works?*
* *What resource issues is your activity facing?*
* *Is there anything that the SSG can do to help?*
* *What funding opportunities could SPARC be pursuing?*

(The information you provide here will guide the discussion at the SPARC SSG meeting).

There are no explicit funding proposals linked to our group. However, SPARC provides a rich and diverse international network of scientists that could be leveraged for funding. We would like to see SPARC taking a lead on e.g. a Marie Curie ITN that leverages SPARC science and connects members.

III. WCRP Communications†

* *What are the data issues/needs for your activity?*

(This information will be communicated to the WCRP Data Advisory Council).

No major updates.

* *What are the modelling issues/needs for your activity?*

(This information will be communicated to the WCRP Modelling Advisory Council).

There are currently no coordinated modeling activities planned within the ATC activity. There are emerging plans for analysis of new CMIP6 simulations available through the ESGF.

IV. SPARC Programmatic Issues

* *What can your activity contribute to the strategic goals formulated in the WCRP strategic plan?*
* *What needs to be formulated in the WCRP Implementation Plan to facilitate this contribution?*

The ATC activity contributes to the following science objectives of the WCRP strategic plan:

1. ***Fundamental understanding of the climate system***

We will support and facilitate the advancement of sciences that enable an integrated and fundamental understanding of the climate, its variations and its changes, as part of a coupled physical, biogeochemical, and socio-economic system.

Atmospheric temperature is an integrative measure of multiple radiative and dynamical processes and is therefore a key variable for climate science. Characterising variations and changes to temperature, and unpicking the multiple external and internal drivers of trends, contributes important, new fundamental understanding of the climate system and its changes over time. It provides a means to challenge models to perform against observations and to generate improvements in modelling where errors are identified.

3. ***Long-term response of the climate system***

We will quantify the responses, feedbacks, and uncertainties intrinsic to the changing climate system on longer (decadal to centennial) timescales.

As described above, one of the key fingerprints of anthropogenic influence on the climate system is through temperature changes that extend from the surface to the upper atmosphere. The ATC activity addresses the characterisation of these climate fingerprints from the development and application of temperature datasets, the evaluation of model simulations of temperature trends and the understanding of the key drivers of temperature changes as a function of altitude and latitude.

In addition to these science objectives, the ATC activity also supports the following strategic priority under Critical Infrastructure:

II. Sustained observations and reference data sets

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 for groups such as IPCC and national climate assessments to characterize how the climate system is changing now and to anticipate any possible surprises in the future.

Implementation Plan

In recent years the WCRP structure has revolved around the four core projects and seven Grand Challenges, which have been fairly autonomous of the core projects. How will this structure change in the future? It would be nice to see a model emerge whereby the core projects work collaboratively to address cross-cutting themes. The emerging cooperation across WCRP on the Earth's energy imbalance is a useful example of how these themes could be run.

* *To which other SPARC or WCRP activities does your activity connect?*
* *Should you be thinking about joint workshops?*
* *Can the SSG do anything to help foster better connections between your activity and other SPARC/WCRP activities?*

(This will also guide the discussion at the SPARC SSG meeting).

The ATC activity has overlapping membership with other relevant SPARC activities including CCMI, SOLARIS-HEPPA, SSiRC, WAVAS and S-RIP. These joint members have facilitated exchanges from other SPARC activities to ATC.

* *Has your activity contributed in any way to SPARC's capacity development effort?*
* *Is there any way the SSG capacity development group can help you to do more?*

The ATC activity currently has no direct link to SPARC's capacity development effort. However, the activity membership has been formulated to support early career scientists and encourage gender balance. We are also keen for the activity to be open to new interested parties and people with relevant expertise from developing countries. If there are opportunities for ATC members to contribute to workshops related to capacity building we are open to contributing to these.

* *Is there anything else that the SSG can do to assist your activity in any way?*

(This will also guide the discussion at the SPARC SSG meeting).

Not at present, but responding to the restructuring of WCRP and arguing the case for the future of SPARC and its science within WCRP is important for all activities.

**** Please also take this opportunity to revisit the material published for your activity on the SPARC web page. (Please communicate any required changes to the SPARC Project Office).***

Publication list update

[†] Issues/needs in this context refers especially to those that may require WCRP engagement beyond SPARC.