SPARC Activity Report 2018
(*LOTUS*)

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? (This material will be incorporated into the Annual Report).

- The first phase of the LOTUS activity is accomplished. The SPARC/WMO LOTUS report successfully went through three anonymous reviews and was accepted in June 2018 (great appreciation to SPARC office for organizing the review process). The LOTUS Report was primarily targeted at providing timely input to the 2018 WMO Ozone Assessment. Main conclusions of the report were incorporated in the 2018 Ozone Assessment Chapter 3. LOTUS activity re-evaluated the satellite and ground-based data records as well as the time series analysis methods commonly used to derive long-term trends. Using a single "LOTUS regression" model, past (prior to 1997) and recent (post 2000) trends were re-assessed in the vertical distribution of stratospheric ozone from the updated individual data records. A new approach to combine the individual trend estimates from satellite-based records into a single best estimate of ozone profile trends was developed that includes combined uncertainty estimates and accounts for drifts between records. Finally, Report provides comparisons between the satellite-based profile trends in broad latitude bands to trends from ground-based data, from the collection of CCMI-1 model simulations, and from past evaluations of satellite-based trends in peer-reviewed literature. To learn more about the Report and its main conclusions please read recently published article in the July 2018 SPARC Newsletter. Expected date for release of the published LOTUS report is the end of 2018, which will be shared on the SPARC webpage.
- The second LOTUS workshop was hosted by the WMO GAW office (Oksana Tarasova and Geir Braathen) in Geneva on September 17-19, 2018. Thirty researchers attended this invite-only workshop (some through remote access) and participated in the 3-day meeting with a selected number of scheduled oral presentations, posters and ample time for discussions. The LOTUS activity group addressed the plans how to resolve the remaining open issues for ozone trend detection identified in the published Report. For example, among analyses issues we face the reconciliation of the stratospheric, tropospheric and total ozone trends. Recent TOAR publications that discussed tropospheric ozone trends found significant datasets differences and thus rates of the global ozone increases particularly in the lower stratosphere remain highly uncertain. Is low stratospheric ozone declining as published by Ball et al. (2018) and can we verify this decline by re-analysing column stratospheric trends from the ground-based observations. Is LOTUS regression model adequate for ground-based records? Can we improve GB data analyses? How can we improve the estimates of trend uncertainties and identify correlation between records? More information can be found at the LOTUS workshop website https://events.oma.be/indico/event/56/timetable/#20180918.detailed. A summary of the workshop report will be published in the January 2018 SPARC Newsletter.
- A website for the LOTUS activity has been inactive. We found that telecon and special sessions at AGU and EGU were the most effective tools to coordinate our activity. We also used Google documents to develop Report documents and guide the discussion of various issues in data trend analsyses. It is understood that the LOTUS activity webpage would

provide a wider public access to the project information, updates, workshop reports and presentations, exchange useful documents, and help in coordination of planning efforts. Thus, we will attempt to reactivate the webpage at http://igaco-o3.fmi.fi/LOTUS

- Several oral presentations were made at symposia, workshops and conferences
    - o Dr. Petropavloskikh presented an invited talk on LOTUS at the SPARC Data Assimilation Working Group (SPARC-DA) and SPARC Reanalysis Intercomparison Project (S-RIP) joint workshop in October 2017 in Reading, UK
    - o Special session "Stratospheric Ozone Change, Its Impact on Climate and Understanding of Uncertainties in Data Records" was organized at the 2018 Fall AGU that featured 12 oral and poster presentations to highlight the SPARC/WMO LOTUS activity, New Orleans, 10-15 December, 2018.
    - o I. Petropavlovskikh presented "LOTUS activity" at UTLS workshop at Mainz, February, 2018
    - o Alexandra Laeng gave presentation "Ozone before and post-1997 trends from merged SAGE II / MIPAS / OMPS satellite ozone record" at DLR Climate Change Conference, 17-19 April 2018, Cologne, Germany
    - o Special session "Advances in estimating and attributing long-term ozone and temperature trends in the middle atmosphere (co-organized)" was organized at EGU that featured 18 oral and poster presentations focused on LOTUS activity, Vienna, April, 2018
    - o Alexandra Laeng gave presentation "Update on ozone trends from merged SAGE / MIPAS / OMPS dataset: are the lower stratospheric trends negative ?" at MIPAS Data User Meeting 15-17 May 2018, Granada, Spain
    - o Stacey Frith presented LOTUS activity overview at CEOS AC-VC meeting in College Park, Maryland, on 2-4 May 2018
    - o Dr. S. Godin-Beekmann presented results of the LOTUS SPARC activity at the Ozone SAG meeting in Jülich (Germany), May, 2018
    - o Dr I. Petropavlovskikh presented "Overview of the Long-term Ozone Trends and Uncertainties in the Stratosphere (LOTUS) SPARC Activity" at the NOAA 46th ESRL Global Monitoring Annual Conference 2018, Boulder, CO, USA, 21-23 May 2018.

- Several papers were published or are currently in review
    - o LOTUS co-leads were co-authors of the 2018 WMO/UNEP Ozone assessment Chapter 3.
    - o Steinbrecht, W., Froidevaux, L., Fuller, R., Wang, R., Anderson, J., Roth, C., Bourassa, A., Degenstein, D. Damadeo, R., Zawodny, J., Frith, S., McPeters, R., Bhartia, P., Wild, J., Long, C., Davis, S., Rosenlof, K., Sofieva, V., Walker, K., Rahpoe, N., Rozanov, A., Weber, M., Laeng, A., von Clarmann, T., Stiller, G., Kramarova, N., Godin-Beekmann, S., Leblanc, T., Querel, R., Swart, D., Boyd, I., Hocke, K., Kämpfer, N., Maillard Barras, E., Moreira, L., Nedoluha, G., Vigouroux, C., Blumenstock, T., Schneider, M., García, O., Jones, N., Mahieu, E., Smale, D., Kotkamp, M., Robinson, J., Petropavlovskikh, I., Harris, N., Hassler, B., Hubert, D., and Tummon, F.: An update on ozone profile trends for the period 2000 to 2016, Atmos. Chem. Phys., 17, 10675-10690, doi:10.5194/acp-17-10675-2017, 2017.
    - o Damadeo, R. P., Zawodny, J. M., Remsberg, E. E., and Walker, K. A.: The impact of nonuniform sampling on stratospheric ozone trends derived from occultation

instruments, Atmos. Chem. Phys., 18, 535-554, https://doi.org/10.5194/acp-18-535-2018, 2018

o Frith, S. M., Stolarski, R. S., Kramarova, N. A., and McPeters, R. D.: Estimating uncertainties in the SBUV Version 8.6 merged profile ozone data set, Atmos. Chem. Phys., 17, 14695-14707, https://doi.org/10.5194/acp-17-14695-2017, 2017.

o Ball, W. T., Alsing, J., Mortlock, D. J., Rozanov, E. V., Tummon, F., and Haigh, J. D.: Reconciling differences in stratospheric ozone composites, Atmos. Chem. Phys., 17, 12269-12302, https://doi.org/10.5194/acp-17-12269-2017, 2017.

o Ball, W. T., Alsing, J., Mortlock, D. J., Staehelin, J., Haigh, J. D., Peter, T., Tummon, F., Stübi, R., Stenke, A., Anderson, J., Bourassa, A., Davis, S. M., Degenstein, D., Frith, S., Froidevaux, L., Roth, C., Sofieva, V., Wang, R., Wild, J., Yu, P., Ziemke, J. R., and Rozanov, E. V.: Evidence for a continuous decline in lower stratospheric ozone offsetting ozone layer recovery, Atmos. Chem. Phys., 18, 1379-1394, https://doi.org/10.5194/acp-18-1379-2018, 2018.

o Zerefos, C., Kapsomenakis, J., Eleftheratos, K., Tourpali, K., Petropavlovskikh, I., Hubert, D., Godin-Beekmann, S., Steinbrecht, W., Frith, S., Sofieva, V., and Hassler, B.: Representativeness of single lidar stations for zonally averaged ozone profiles, their trends and attribution to proxies, Atmos. Chem. Phys., 18, 6427-6440, http://doi.org/10.5194/acp-18-6427-2018, 2018.

- An FTP archive was set up by FMI to collect the ozone measurement datasets for ozone trend assessment and proxy parameters used in the regression analyses. Results of the trend analyses and various sensitivity tests have been archived. The data and results will be made available to the public after the report is submitted for review.

* 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).

- The Final Report will be published by SPARC by the end of October 2018. The Report will contain information about the ozone records, their stability, measurement uncertainties, multiple regression models, sensitivity tests, trends and their uncertainties. Key results by LOTUS will also appear as part of the WMO/UNEP Ozone Assessment to be published in 2018.

- Several research projects in LOTUS activity were not mature enough for inclusion in the final Report. At the Second LOTUS workshop in Geneva (September 17-19, 2018) a list of remaining open issues relevant to the ozone profile trend study was identified (i.e. UTLS, polar regions, seasonality of trends, trends at upper altitudes, discrepancies in ground-based and satellite trends, optimization of the LOTUS trend model for detecting trends in low stratosphere and attribution to dynamical processes). Participants discussed upcoming changes to some combined and ground-based datasets that will include correction of drifts and instrumental re-characterization issues in individual instrumental records. Extended and revised datasets will be submitted to the LOTUS ftp site for the second phase of the data analyses by 2019. Further collaborations on determining specialized/optimized datasets and analyses to address these issues will be included in the next year activities (through telecon discussions and attending scientific conferences). Participants of the workshop identified topics of several unresolved issues and formed collaborations. The list of the new research topics and names of contributors will be

published on the LOTUS webpage. Also, LOTUS will continue investigation of the impact of measurement uncertainties on the derived trends and the use of level 2 data to reconcile instrumental record biases and associated step changes remaining in combined records (BASIC approach in collaboration with the TUNER SPARC activity). Collaborative project will result in the papers.

- The IUGG GA will be held in Montreal, Canada in July 2019. Session "Celebrating the Montreal Protocol in Montreal: assessing Ozone Layer Recovery in an Evolving Climate." will focus on topics that largely overlap with LOTUS activity. There will be several abstracts submitted by LOTUS participants to the session.
- A special session "Long-term Ozone Trends and Estimation of their Associated Uncertainties" will be organized at the AGU Fall meeting in San Francisco, in December 2019. Also, the LOTUS-focused session "Advances in estimating and attributing long-term ozone and temperature trends in the middle atmosphere" was proposed for EGU to be held in April 2019.

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).

The next workshop is planned for 2019. Details are still discussed, but there is proposal to hold it adjacent to OCTAV-UTLS activity workshop (planned for Boulder, Colorado in summer of 2019) to promote collaboration in the areas of common interests. LOTUS activity initiated collaborations to align its ongoing assessment of the ozone trends in UTLS region with OCTAV-UTLS activity. WCRP/SPARC funding is requested to support travel for two early career scientists from North America and one from Europe. There is another opportunity to align the workshop with the IUGG GA meeting that will be held in Montreal, Canada on July 8-15, 2019.

* 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).

We are working across different national programs to identify opportunities for funding. Most of current participants in LOTUS activity have financial support and plan to continue their investigations. However, we just lost funding for a postdoc who was working on LOTUS trend analyses. Thus, we are looking for the replacement. Funding is needed to bring young scientists (including postdocs) into the activities. The postdoc opportunities can be supported by SPARC in collaboration with educational institutions that have interest in sharing the funding across the broader collaborations, including the tutorship from established scientists. One opportunity is to seek support from Copernicus and other programs that are interested in developing uncertainty budget for the ozone records (C3S and ACTRIS programs).

III. WCRP Communications[1]
* What are the data issues/needs for your activity? (This information will be communicated to the WCRP Data Advisory Council).

The issue of comparing the datasets that have different reference grids (pressure vs altitude) is of importance for trend analyses. The non-uniform sampling issues affect the representativeness of monthly and zonally averaged data and thus can alias into the trend and uncertainties. We must work closely with the reanalysis centres' representatives and with the SPARC Reanalysis Intercomparison Project (S-RIP).

The LOTUS generated datasets will be made available to the public. The archive is currently supported by Finnish Meteorological Institute that hosts the archive. It is not clear at this point for how long they will be able to host the datasets. There is a need to develop a policy for the support of datasets and products from the SPARC activities. It would be also great to generate DOI numbers for some of the datasets... and the developed regression code.

* What are the modelling issues/needs for your activity? (This information will be communicated to the WCRP Modelling Advisory Council).

LOTUS data sets and trend results are to be compared to model results from the CCMI activities. A close cooperation with scientists involved in CCMI related ozone trend analyses is needed for the interpretation of trend results in the various regions of the stratosphere.

Estimating trends in the lower stratosphere and upper troposphere is complicated due to sampling issues in observation systems and large dynamical variability. Transport modelling -- e.g., chemical transport modelling and trajectory analysis -- will be needed later in the project to obtain geophysical representation of dynamical proxies and volcanic aerosol variability for sampling at the ground station and interpretation of zonally (or more representative coordinate) averaged data. It is especially important for analyses of ozone in UTLS region near the subtropical jet locations. New coordinate systems using parameters such as the dynamical tropopause, potential temperature and subtropical jet locations will also be useful for that objective. Assimilated ozone and modeled (e.g., from chemistry climate models) composition data will be used to test sampling issues and measurement system biases. We will collaborate with OCTAV-UTLS project that will provide a database and toolkit for more comprehensive evaluation of climate models in the UTLS.

IV. SPARC Programmatic Issues
* 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).

LOTUS has established collaborations with several SPARC Activities that have shared goals and expertise:

---

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

- Information from the SPARC emerging activity TUNER (Towards Unified Error Reporting) will provide critical information on measurement characteristics and uncertainties needed for combining the multi-platform datasets for LOTUS studies. TUNER co-leads Thomas von Clarmann (KIT/IMK, Karlsruhe Germany), Doug Degenstein (Univ. Saskatchewan, Canada) and Nathaniel Livesey (NASA JPL, Pasadena, USA) are members of the LOTUS activity.
- The S-RIP activities are critical to the LOTUS effort for the understanding which models can provide the data for comparisons with observations to characterize past and future ozone trend for attributions to the ODS and climate. Dr. Sean Davis is a co-lead of the Climatology and Interannual Variability project and an active participant in LOTUS activity; other LOTUS team members are also involved in these activities.
- CCMI (the Chemistry Climate Model Initiative) will benefit from collaborations with LOTUS that can provide assessed ozone datasets and trend attribution products that can be applied to chemistry climate model. Several members of LOTUS members are participants in CCMI activities.
- The OCTAV-UTLS activity is an important partner for future trend analyses of ozone in the UTLS region. The new products provided from the activity will help to interpret ozone trends, reduce uncertainties due to dynamical variability in the region and create methods for understanding impacts of the climate changes to ozone levels in UTLS.

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?

We have not yet made a direct contribution towards supporting capacity development efforts. However, we expect to have more opportunities once the Report will be published and distributed to the SPARC community. By setting up the website and presenting at variety of meetings we have begun collaboration with SPARC community regarding trend analyses methods, uncertainties and stability of measurements, ability of models to capture past trends, and attributions to the ODS reduction. The statistical models and results of trend analyses will be made available to all interested parties. The LOTUS project is using ozone-sonde datasets provided by facilities in developing countries, and is planning presentations in some of those regions when members of the team visit these facilities. The LOTUS participants will share gained knowledge with researchers at these facilities to enhance data analysis opportunities. Additional funding from SPARC would certainly help develop collaboration with institutions from developing countries in terms of trend analyses.

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).

We would appreciate any guidance on how we can become more involved in capacity development activities. Financial support of workshops will also be welcome.

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).

We will provide updates for the LOTUS material on the SPARC Website within the next few weeks. We are collecting publication list that we will submit for the updates.