Milestone 10.3: Guidelines for communication and public relations

Authors: Silja Häme (UHEL), Giulia Saponaro (FMI), Stephany Mazon (UHEL)

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Contents

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1. Science communication guidelines

This document presents the guidelines for communication and public relations for Aerosol, Trace Gases and Clouds Research Infrastructure (ACTRIS) prepared as a milestone for ACTRIS IMP project. The guidelines are prepared during the implementation phase of ACTRIS, but they are applicable also after the ACTRIS becomes fully operational (expected in 2026). As ACTRIS is developing as a global research infrastructure, our attention is focused on liaisons. To this end, we developed these communication guidelines to support ACTRIS internal community with a coordinated approach towards external communication. ACTRIS internal communication strategy is presented in ACTRIS IMP D10.1 Updated plan for communication within ACTRIS (here).

1.1 Objective

For the ACTRIS to be impactful, it is necessary to engage with academic and non-academic audiences to inform about the ACTRIS research processes, results and impacts. Any member of the ACTRIS community (for example project beneficiaries, members of the Central Facilities, National Contact Persons, National Facilities PIs) are encouraged to act as an ACTRIS spokesperson and proactively engage in the communication and dissemination activities to promote ACTRIS. The communication format and channels vary depending on the target audience and desired outcome (inform, promote, seek collaborations or funding, etc.) A detailed description of ACTRIS communication guidelines, target groups, channels, roles and task responsibilities has been defined in ACTRIS IMP D10.1 –"Updated plan for communication within ACTRIS".

It is important to communicate about science performed within ACTRIS. This will (1) provide an expert source of information to the public, media, decision-makers, (2) make science and scientific concepts accessible and understandable to the public, (3) promote and make visible ACTRIS research and impact, (4) increase visibility of ACTRIS research and researchers within the international scientific community, (5) enable co-creation of material for project reporting and funding proposals. For advice on communication channels and formats, one should contact the (Interim) ACTRIS Head Office communications officer.

1.2 Best practices for science communication at ACTRIS

The materials of the ACTRIS science communications (press releases, videos, social media content for the ACTRIS accounts) are created in cooperation between the ACTRIS internal stakeholders and the Head Office. ACTRIS spokespersons may give media interviews on the topics of their competence area on behalf of ACTRIS. ACTRIS Head Office offers support in preparing for an interview. There is an ACTRIS slide set available in the ACTRIS intranet (here) incl. slides describing ACTRIS in general, ACTRIS observational components, used measurement techniques, ACTRIS National Facilities, ACTRIS impact, collaboration, science policy contribution etc. It is recommended that these slides are used e.g., when preparing for the interview or presenting ACTRIS to external audiences. If the journalist is in direct contact with the ACTRIS representative (i.e., ACTRIS community member), and there is special media visibility expected, it is recommended that the Head Office is informed of this.

Media releases are made on a case-by-case basis on topics which are of interest to the media. The audience of the science news are, for example, the media, funders, and citizens. The ACTRIS representative shall be in contact with ACTRIS Head Office to make a press release or other media contact. For articles in national newspaper, the ACTRIS national contact point could act as an interface between the media and the ACTRIS Head Office. Science news drafts should be sent to ACTRIS Head Office as soon as there is knowledge that the article will be published. For example, press releases are made when e.g.:

- publishing a study in high-impact scientific journal
- at the beginning or end of an ACTRIS related research project
- interesting interim results have been reached
- the ongoing research is significant for public discussion, topical issues, or society
- an interesting research expedition is coming up, or practical studies or measurements are being carried out at an interesting location
- a dissertation or report is about to be completed.

Regarding the visual identity and materials, there are graphic guidelines explaining how to use ACTRIS visual identity. When representing ACTRIS, always use ACTRIS visual identity, e.g., power point templates, logo, etc. Find an overview of ACTRIS communication portfolio in ACTRIS IMP D10.2 Creation of dedicated communication portfolio (here).

It should be noted that a Research Performing Organization (RPO) publishing a scientific article on ACTRIS related research and activities is in charge of promoting the article. In order to enhance the visibility of the article and overall to support the promotion of ACTRIS activities, the RPO should make ACTRIS Head Office aware of its outputs contacting the Head Office e.g., via email so that the Head Office can communicate the outputs via ACTRIS communication channels. ACTRIS Head Office has built an extensive network that will boost and elevate the individual RPO communication outputs to European and international level. To ensure proper acknowledgements in scientific articles that have used ACTRIS project funding (e.g., transnational access funding from ACTRIS IMP) the needed information for the acknowledgement should be easily available at the ACTRIS website. In case of ACTRIS IMP project' transnational access: "This work has been supported by the ACTRIS IMP (TransNational Access Programme) of the European Commission: grant agreement No 871115."

2. Communication channels

2.1 Science outreach platforms

Communication and interaction are an increasingly central part of research and, consequently, of planning research projects. Most funders require a plan and reporting on how funded projects have communicated on their research and on the impact of their research. Information on ACTRIS related outreach activities need to be provided to ACTRIS Head Office in a timely manner to enhance the visibility of these activities at European and international levels and for internal reporting purposes.

Platforms for science outreach are at least the following with short summaries in and target audiences listed in the section below:

1. Video
2. Podcast
3. Blog
4. Comics / art
5. Illustrations / Infographics
6. Social media campaigns

It should be noted that the communication activities need resources (funding and personnel). The forms of communication (e.g., videos) taking up a lot of resources shall not be used as the main communication channel or for frequent communication.

1. The videos are the fastest growing way to communicate information as they can quickly grab the audience attention. It is a preferred format for quick communication of information over images and, lastly, text. A customized Channel can be created, such as in Vimeo or Youtube, to form a library of videos. This format is useful when introducing for example research infrastructures, locations, people, or projects, as well as serve as educational material. While it may take time and effort to learn to make a video, once it is uploaded it can reach a worldwide audience and remain permanently online. This makes it a very versatile format to use.

<u>Audience: public, research community, students, funding agency</u>

2. Podcast interview or alternatively, a research group can release a series of podcasts. Each episode can cover a different topic or expert. Podcast interviews can be a safe way to interview a nervous researcher, as they can be edited, cutting out mistakes or long silences. Once a podcast audio file is ready, it is easily sharable across various platforms like Spotify, iTunes, SoundCloud, increasing the audience reach.

<u>Audience: public</u>

3. A blog serves as an informal diary that offers updates into, for examples, a research project / campaign / experiment / research group / personal researcher. Blog formats are chronological short texts and photographs, often written in a personal tone of voice.

<u>Audience: public, specialized community</u>

4. Comics are a growing medium to communicate. The comic format is short or long (graphic novel) content, where the focus is on the illustrations accompanied by few lines of texts (sometimes in dialogue or thought bubbles). One good example of research comics are the ERC Comics (find the weblink below), and the 2021 IPCC comics (see reference below).

Audience: public

Because IPCC – A Free Graphic Novel – History and Science of the Intergovernmental Panel on Climate Change by https://becauseipcc.science/

ERCcOMICS – https://www.erccomics.com/

5. Illustrations and infographics can be used to summarize a research article, a project idea, or a concept. Illustrations and infographics can be shared on websites, social media and presentations together with e.g. links to research articles, website, and other sources for further information.

An example of a climate infographics is the 'climate stripes' by Ed Hawkins.

Audience: public, research, reports, proposals

6. Social Media campaigns. Among the 3 largest platforms of Social Media are Twitter, Facebook and Instagram (Hootsuite Report 2021), and can be used to share publications, events, job vacancy, research activity updates, as well as live-streaming events. Specific uses relevant for researchers include e.g. links to university websites, publication links to pdfs, photographs and videos of research activity, live-streaming of talks or measurement process. Using associate keywords to the post using the #hashtag symbol, allows the online community that is following the #keyword to come across our posts.

Multiple-day events like conferences can use an associated #Keyword to create 'buzz' around the topic. Highly talked-about #keywords can appear in the top 10 local/regional/international Keywords list, further prompting twitter uses to come across it.

2.2 Press releases and interviews to communicate research outcomes to wider audiences

One can publicize research outcomes in press releases or interviews.

Press release: Press release draft to be prepared and and shared with the ACTRIS Head Office communications team as soon as possible. A good timeframe is 2-3 weeks before the paper comes out. The press release draft can be 1 page long and should use language without scientific jargon.

Interviews: One doesn't have to be an expert public speaker to be a good candidate for a news interview, and each experience will serve as a practice.

1. Being interviewed for a publication or project – one needs to be sure how to explain the concepts in general terms and how it is relevant to society: it could offer new knowledge, be relevant for regulations, involve the local community.
2. Being interviewed to give an insight as an expert to a broader topic – one may be contacted to give an expert comment on, e.g., Anthropogenic emissions on behalf of ACTRIS. As the questions could be broader in scope, some key messages relevant to the topic should be prepared beforehand. No scientific detail is needed. Instead, an insight into the overall process, frequency, outlook, or possible impacts can be provided. If it is possible, the interviewer can be asked to provide possible questions to enable preparations in advance.
3. List of interviews should be provided to the ACTRIS HO for added visibility and for internal reporting purposes.

3. Case Study: ACTRIS and IPCC

The mission of ACTRIS is to facilitate high-quality Earth system research. ACTRIS provides information on the composition and variability and of the physical, optical, and chemical properties of short-lived atmospheric constituents, from the surface throughout the troposphere to the stratosphere, with the required level of precision, coherence, and integration. Substantial visibility and impact for the high-quality research performed by ACTRIS community can be obtained e.g., by being part of the Intergovernmental Panel for Climate Change (IPCC) report assessing the science related to climate change. We have examined the use of ACTRIS science in the latest IPCC report (IPCC, 2021) (*see Appendix I for details*). ACTRIS is directly mentioned in the IPCC 2021 report once in Chapter 1 Framing, context, and methods (section 1.5.1.1. Major expansions of the observational capacity) as an example of an expanded atmospheric composition observation networks together with ICOS (Integrated Carbon Observation System) and IAGOS (In-service Aircraft for a Global Observing System). In addition to this, over 20 articles from the ACTRIS community are included in the report, especially in the Chapter 6 focusing on short-lived climate forcers.

Use of ACTRIS science in the IPCC report

Why this is important? Use of ACTRIS science in the IPCC report highlights the scientific impact of ACTRIS. IPCC combines novel state-of-the-art scientific peer-reviews results on climate change. In the scientific community and media, the IPCC reports are broadly viewed as the most comprehensive and reliable assessments on climate change. The IPCC has been awarded the Nobel Peace Prize (2007) on its work on climate change.

To whom this is relevant? Scientists, politicians (ministries), citizens interested in the topic.

How to communicate? Documentation, infographics and presentations easily applicable by the ACTRIS community to be used in their own presentations; digital campaign to promote ACTRIS in the IPCC report at ACTRIS website.

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4. Case Study: ACTRIS facilitating innovation and collaboration with the private sector

ACTRIS continuously contributes to new innovations through the work on technology development of its RPOs and Topical Centres. Regarding communication on ACTRIS and innovation/private sector, the main role of ACTRIS Head Office is in knowledge transfer and enhancing the visibility of opportunities related to co-operation with the private sector. ACTRIS communication shall be targeting opportunities for joint private-public ventures and ACTRIS shall act as matchmaker in technology and innovation events. ACTRIS Service and Access Management Unit of the Head Office – SAMU provides a single-entry point for private companies to access to ACTRIS services (e.g., access to certain ACTRIS facilities). ACTRIS works towards the development of an innovation platform to stimulate a more open technology transfer approach within ACTRIS, for disseminating relevant research outputs on atmospheric science to the private sector and for enhancing the collaboration between National and Central Facilities operators and the private sector. It should be highlighted that ACTRIS IMP WP3 D3.1 Innovation Strategy presents examples of success stories showcasing the innovations relating to ACTRIS.

<u>Organization of technology and innovation events:</u>

Innovation in Atmospheric Sciences Virtual Workshop was organized as part of ACTRIS Implementation project in May 2021 (ACTRIS IMP MS12). The workshop brought together atmospheric science communities to discuss the latest innovations in the field and provided information on new technologies, products, services, and instrumentation and access to unique opportunities for networking and R&D collaborations. The workshop was a partner event of the EU Green Week 2021. The workshop was highly successful gathering almost 400 participants from 45 countries and created a unique platform for networking and knowledge-exchange between key contacts from academia, private companies, the public sector and non-governmental organizations (NGOs). Presenters came from universities, research institutions and private companies from across Europe and beyond.

From the communication point-of-view the workshop was actively advertised within ACTRIS and outside communities vie e-mails and advertisements on e.g., ACTRIS website. Partnership the EU Green Week enhanced the event visibility. This kind of partnerships will be also considered in the future to increase the event attendance by companies/NGOs/ other scientific communities/public outside of the ACTRIS community.

ACTRIS and innovation / private sector
Why this is important? Interaction and cooperation with the innovation/private sector is important to e.g., enhance ACTRIS impact on technology development and the establishment of new business ideas and spin-off companies. ACTRIS needs to clearly show what it offers to private companies, and what is the added value of ACTRIS in relation to the private sector.
To whom this is relevant? Academia, private sector, funders.

How to communicate? Promotion of ACTRIS platforms for private sector users e.g., via ACTRIS website (ACTRIS user and access service platform), publication of specific success stories, distributing information to the private sector users directly (e-mail list) and widely in relevant events. It will be ensured that the communication is clear and concise.

5. Case Study: Social impact

As an example of significant ACTRIS societal impact we present the recognition of ACTRIS role during the COVID-19 pandemic in Europe (2020-). The need for atmospheric composition data to address air quality impacts of COVID-19 lockdowns underlined the societal impact of ACTRIS data. ACTRIS has actively participated in rapid and open data provision related to atmospheric composition particularly during the COVID-19 lockdown period. ACTRIS Data Centre has provided a suite of near-real time data to address impacts of the lockdown. This has resulted in several scientific publications capitalizing the pan European context of ACTRIS observations. The ACTRIS data has been crucial in assessing the impacts of COVID-19 lockdown and enabled to disentangle the synoptic weather conditions as the ACTRIS stations have provided extensive pan European database from the pre-lockdown atmospheric composition to contrast the lockdown period (e.g., Torkmahalleh et al. 2021).

In addition to provision of ACTRIS data, ACTRIS National Facilities (simulation chambers) have been used to test the filtering efficiency of personal protective equipment (PPE) of the respiratory system (masks, medical drapes, etc.). E.g., the Institute of Chemical Process Fundamentals of the Czech Academy of Sciences (ICPF) performed tests of size-resolved filtration efficiency for several dozen companies (testing over 250 different types of the PPE).

The ACTRIS response to the pandemic from the communication point-of-view is provided by Saponaro et al. 2021 where the various ACTRIS communication actions are described. ACTRIS response has been communicated on the ACTRIS website (https://www.actris.eu/news-events/news/actris-activities-connected-covid-19-and-lockdown-europe-0), ACTRIS Newsletter, and widely in conferences and workshops.

Social impact of ACTRIS

Why this is important? ACTRIS brings value to societies e.g., through accurate and reliable atmospheric observations and decision-making support for national and local authorities. It is important to recognize how ACTRIS affects the society and extract success stories that involve and have direct impact on people outside the academia. E.g., personal protective mask filtering testing supports consumers to better trust the products they use due to accredited testing of the product.

To whom this is relevant? Society in general, especially non-scientific audience.

How to communicate? Based on the content type, we will use suitable material to be created to match the event/action. When it comes communicating to audiences outside of academia, it will be ensured that the language used is understandable by the general audience.

6. Crisis communication

6.1 What is crisis communication about?

Crisis refers to an unpredictable, rapidly advancing situation that affects or threatens ACTRIS reputation or the operations, personnel or products of ACTRIS. In the event of an accident or some other crisis, it is highly important that the right people get the right information at the right time.

6.2 Objectives of crisis communication

The objectives of crisis communications are to

- help identify potential crises in advance or as early as possible
- prevent damage and accidents (material or reputational)
- provide clear and accurate information
- support efficient operations during a crisis
- help shorten the acute stage of the crisis and minimize the damage caused by the crisis
- show various actors the ACTRIS ability to manage a crisis
- help recover from the crisis and speed up the recovery of operations
- protect and support the ACTRIS' reputation
- ensure uniform communications.

6.3 ACTRIS principles of crisis communication

ACTRIS crisis communications should be open, exhaustive, truthful, and fast. If any member of the ACTRIS community notices a threatening or beginning of a crisis, one should report it immediately to ACTRIS Head Office and potentially also to relevant ACTRIS National Contact Person/(-s) in case of e.g., an environmental crisis such as such as volcanic eruption that may have more local/national effects. One should not spread assumptions and/or rumors. One should rely on ACTRIS contingency plan. ACTRIS contingency plan for implementation and risk management strategy and risk registry will be developed during the IMP project (ACTRIS IMP D2.1 Contingency plan for implementation). In the event of a crisis, an agreement will be made immediately on who will provide additional information to the public (e.g., ACTRIS ERIC Director General, ACTRIS ERIC Head Office Leader, ACTRIS ERIC Head of Communications, relevant ACTRIS National Contact Person). In crisis, ACTRIS Head Office first communicates to the ACTRIS community and only after that to the external parties. Communications are carried out through ACTRIS regular communication channels (incl. e-mails, intranet, ACTRIS website, twitter). In close co-operation with the ACTRIS Head Office, ACTRIS National Contact persons are responsible in communicating about the crisis further in their own countries. If a member of the ACTRIS community plans to spread the information further in twitter, national news etc., she/he is encouraged to contact ACTRIS Head Office to make sure to have the latest information to be shared. And vice versa, ACTRIS Head Office can amplify these type of communication efforts via ACTRIS communication channels.

References

ACTRIS IMP D10.1 Updated plan for communication

ACTRIS IMP D10.2 Creation of dedicated communication portfolio

ACTRIS slide set: https://intranet.actris.eu/index.php/s/4D6Z3PAAgG4wbCK

ACTRIS activities connected to the COVID-19 and lockdown in Europe: https://www.actris.eu/news-events/news/actris-activities-connected-covid-19-and-lockdown-europe-0

IPCC, 2021: *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. *Disclaimer: The Summary for Policymakers (SPM) is the approved version from the 14th session of Working Group I and 54th Session of the Intergovernmental Panel on Climate Change and remains subject to final copy-editing and layout.*

Saponaro, G., Dubost, A., Juurola, E., and Laj, P.: Communicating ACTRIS science in times of COVID-19, EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8622, https://doi.org/10.5194/egusphere-egu21-8622, 2021.

Torkmahalleh, M.A., Akhmetvaliyeva, Z., Omran, A.D., Omran, F.D., Kazemitabar, M., Naseri, M., Naseri, M., Sharifi, H., Malekipirbazari, M., Adotey, E.K., Gorjinezhad, S., Eghtesadi, N., Sabanov, S., Alastuey, A., de Fátima Andrade, M., Buonanno, G., Carbone, S., Cárdenas-Fuentes, D.E., Cassee, F.R., Dai, Q., Henríquez, A., Hopke, P.K., Keronen, P., Khwaja, H.A., Kim, J., Kulmala, M., Kumar, P., Kushta, J., Kuula, J., Massagué, J., Mitchell, T., Mooibroek, D., Morawska, L., Niemi, J.V., Ngagine, S.H., Norman, M., Oyama, B., Oyola, P., Öztürk, F., Petäjä, T., Querol, X., Rashidi, Y., Reyes, F., Ross-Jones, M., Salthammer, T., Savvides, C., Stabile, L., Sjöberg, K., Söderlund, K., Raman, R.S., Timonen, H., Umezawa, M., Viana, M., Xie, S. (2021). Global Air Quality and COVID-19 Pandemic: Do We Breathe Cleaner Air? Aerosol Air Qual. Res. 21, 200567, https://doi.org/10.4209/aaqr.200567.

Appendix I. ACTRIS in IPCC 2021 report

ACTRIS is part of the IPCC 2021 report through articles in peer-reviewed journals that are the core of the IPCC assessment. In order for a paper to be assessed in the IPCC report, it must be accepted for publication or published by a certain date. **As a guideline for communications this cut-off date is important to be communicated with the ACTRIS community to ensure as many novel ACTRIS papers to be available for the assessment as possible.** For the IPCC 2021 report, the cut-off date for submitted papers was 1st November 2020 i.e., around one year prior to the publication of the report.

ACTRIS is directly mentioned in the IPCC 2021 report once in Chapter 1 *Framing, context, and methods* (section 1.5.1.1. *Major expansions of the observational capacity*), see Table 1. In addition to this, over 20 ACTRIS related papers are included in the report, especially in the Chapter 6 focusing on short-lived climate forcers (see Table 1). A concise document on the use of ACTRIS science in such important assessments as IPCC should be openly available for ACTRIS community's use e.g., show direct citations from the report in presentations.

Table 1. In this table we show where ACTRIS related papers have been referred to in the IPCC 2021 report and cite IPCC report text. ACTRIS as such is mentioned once in the report. In addition to this there are several ACTRIS related papers referred to in the report. The ACTRIS references are bolded in the cited text. ***Disclaimer: The Summary for Policymakers (SPM) is the approved version from the 14th session of Working Group I and 54th Session of the Intergovernmental Panel on Climate Change and remains subject to final copy-editing and layout.***

Chapter 1. Framing, context, and methods, 1.5.1.1 Major expansions of observational capacity:
"Observations of the composition of the atmosphere have been further improved through expansions of existing surface observation networks (Bodeker et al., 2016; ***De Mazière et al., 2018****) and through in situ measurements such as aircraft campaigns (Chapter 2, Section 2.2; Chapter 5, Section 5.2; Chapter 6, Section 6.2).* ***Examples of expanded networks include Aerosols, Clouds, and Trace Gases Research InfraStructure (ACTRIS) (Pandolfi et al., 2018), which focuses on short-lived climate forcers****, and the Integrated Carbon Observation System (ICOS), which allows scientists to study and monitor the global carbon cycle and greenhouse gas emissions (Colomb et al., 2018). Examples of recent aircraft observations include the Atmospheric Tomography Mission (ATom), which has flown repeatedly along the north-south axis of both the Pacific and Atlantic oceans, and the continuation of the In-service Aircraft for a Global Observing System (IAGOS) effort, which measures atmospheric composition from commercial aircraft (Petzold et al., 2015)."*
De Mazière, M. et al., 2018: The Network for the Detection of Atmospheric Composition Change (NDACC): history, status and perspectives. *Atmospheric Chemistry and Physics*, 18(7), 4935–4964, doi:10.5194/acp-18-4935-2018. **(many of European NDACC sites are also ACTRIS stations)**

Pandolfi, M. et al., 2018: A European aerosol phenomenology – 6: scattering properties of atmospheric aerosol particles from 28 ACTRIS sites. *Atmospheric Chemistry and Physics*, **18(11)**, 7877–7911, doi:10.5194/acp-18-7877-2018. **(28 ACTRIS sites)**
Chapter 2. Changing state of the climate system, 2.2 Changes in Climate Drivers; 2.2.6 Tropospheric aerosols:
"Spatially resolved trends of AOD derived from Aqua/Terra MISR and MODIS instruments over 2000–2019 range between -2% and 2% per year (Figure 2.9c). Ground-based solar attenuation networks help to constrain and improve the satellite-derived retrievals of AOD, and trends derived from the AERONET network (Figure 2.9c, d) corroborate satellite results (Bauer et al., 2020; Georgoulias et al., 2016; Wei et al., 2019; Yu et al., 2020) in particular for declines over Europe (Stjern et al., 2011; Cherian et al., 2014; ***Li et al., 2014****) and the USA (Jongeward et al., 2016; Li et al., 2014). The tendency in AOD over East Asia reversed from positive (2000–2010) to negative (since 2010) (Filonchyk et al., 2019; Ma et al., 2019; Samset et al., 2019; Sogacheva et al., 2018). Over southern Asia, however, AOD from satellite (MODIS / MISR) and AERONET retrievals show continuing increases (Li et al., 2014; Zhao et al., 2017), with similar trends from UV-based aerosol retrievals from the Ozone Monitoring Instrument (OMI) on the Aura satellite (Dahutia et al., 2018; Hammer et al., 2018). A comparison of MODIS and MISR radiometric observations with the broadband CERES satellite instrument (Corbett and Loeb, 2015) showed that drifts in calibration are unlikely to affect the satellite derived trends. CERES shows patterns for clear-sky broadband radiation consistent with the aerosol spatio-temporal changes (Loeb et al., 2018; Paulot et al., 2018).* *Satellite-derived trends are further supported by in situ regional surface concentration measurements, operational since the 1980s (sulphate) and 1990s (PM2.5) from a global compilation (Coen et al., 2020) of networks over Europe (Stjern et al., 2011), North America (Jongeward et al., 2016), and China (Zheng et al., 2018).* ***Collaud Coen et al. (2020)*** *report from surface observations across the NH mid-latitudes that aerosol absorption coefficients decreased since the first decade of the 21st century."*
Collaud Coen, M. et al., 2020: Multidecadal trend analysis of in situ aerosol radiative properties around the world, *Atmospheric Chemistry and Physics*, **20**, 8867–8908, https://doi.org/10.5194/acp-20-8867-2020. **(GAW stations that are also ACTRIS sites)** Li, J., B.E. Carlson, O. Dubovik, and A.A. Lacis, 2014: Recent trends in aerosol optical properties derived from AERONET measurements. *Atmospheric Chemistry and Physics*, **14(22)**, 12271–12289, doi:10.5194/acp-14-12271-2014 **(AERONET EUROPE includes ACTRIS stations)**
Chapter 6. Short-lived climate forcers, 6.2 Global and regional temporal evolution of SLCF emissions; 6.2.1 Anthropogenic sources:
"For SO2, independent emission inventories and observational evidence show that on a global scale strong growth of Asian emissions has been countered by reduction in North America and Europe (Reis et al., 2012; Amann et al., 2013; Crippa et al., 2016; Aas et al., 2019). Since about 2006, also Chinese emissions declined by nearly 70% by 2017 (Silver et al., 2018; Zheng et al., 2018b; ***Mortier et al., 2020****; Tong et al., 2020) (high confidence). The estimated reduction in China contrasts continuing strong growth of SO2 emissions in South Asia (Figure 6.19). In 2014, over 80% of anthropogenic SO2 emissions*

originated from power plants and industry with Asian sources contributing more than 50% of total (Figure 6.3).”
Mortier, A. et al., 2020: Evaluation of climate model aerosol trends with ground-based observations over the last 2 39 decades – an AeroCom and CMIP6 analysis. Atmospheric Chemistry and Physics, 20(21), 13355–13378, 40 doi:10.5194/acp-20-13355-2020. **(incl. GAW and AERONET stations that are also ACTRIS stations)**
Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances:
*“**BOX 6.1: Atmospheric abundance of SLCFs: from process level studies to global chemistry-climate models*** *Process-level understanding of tropospheric gas and aerosol chemistry developed through laboratory and simulation chamber experiments as well as quantum chemical theory is used to generate chemical mechanisms. Atmospheric simulation chambers are designed to identify the chemical pathways and quantify reaction kinetics in isolation from atmospheric transport, deposition and emission processes. Ideally the chemical regimes studied, are representative for ambient atmospheric complexity and concentrations (e.g., **McFiggans et al., 2019**).”*
McFiggans, G. et al., 2019: Secondary organic aerosol reduced by mixture of atmospheric vapours. *Nature*, **565(7741)**, 587–593, doi:10.1038/s41586-018-0871-y. **(ACTRIS platform Jülich chamber, Germany)**
Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances; 6.3.3.2 Carbon Monoxide (CO):
*“Since AR5, advances in satellite retrievals (e.g. Worden et al., 2013; Warner et al., 2014; Buchholz et al., 2021a), ground based column observations (e.g. Zeng et al., 2012; Té et al., 2016), airborne platforms (e.g. Cohen et al., 2018; Petetin et al., 2018), surface measurement networks (e.g., Andrews et al., 2014; Petron et al., 2019; Prinn et al., 2018; **Schultz et al., 2015**) and assimilation products (e.g., Deeter et al., 2017; Flemming et al., 2017; Zheng et al., 2019) have resulted in better characterization of the present day atmospheric CO distribution. Typical annual mean surface CO concentrations range from ~120 ppb in the Northern Hemisphere to ~40 ppb in the Southern Hemisphere (Petron et al., 2019). The sub-regional patterns in CO reflect the distribution of emission sources. Seasonal hotspots are linked to areas of biomass burning in tropical South America, equatorial Africa, Southeast Asia, and Australia. A study using data assimilation techniques estimates a global mean CO burden of 356 ± 27 Tg over the 2002-2013 period (Gaubert et al., 2017).”* *“**Table 6.4:** Summary of the global CO trends based on model estimates and observations.” [includes **Angelbratt et al., 2011**]*
Schultz, M.G. et al., 2015: The Global Atmosphere Watch reactive gases measurement network. *Elem Sci Anth*, **3(0)**, doi:10.12952/journal.elementa.000067. **(some of the GAW sites are also ACTRIS sites)** Angelbratt, J. et al., 2011: Carbon monoxide (CO) and ethane (C2H6) trends from ground-based solar FTIR measurements at six European stations, comparison and sensitivity analysis with the EMEP model. *Atmospheric Chemistry and Physics*, **11(17)**, 9253–9269, doi:10.5194/acp-11-9253-2011. **(ACTRIS sites**

from Germany (Bremen, Ny Ålesund, Zugspitze) and one from Switzerland (Jungfraujoch) involved) (only CO data mentioned in the IPCC report).
Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances; 6.3.5 Aerosols:
*"Remote sensing instruments provide a larger-scale view of aerosol distributions and trends than ground-based monitoring networks by retrieving the Aerosol optical depth (AOD), which is indirectly related to aerosol mass concentrations. AOD is the column-integrated aerosol mass extinction at a given wavelength, and is therefore relevant to the estimation of the radiative forcing of aerosol-radiation interactions (Section 7.3.3.1). Models participating in Phase III of the AeroCom intercomparison project were found to underestimate present-day AOD by about 20% (**Glìß et al., 2020**), although different remote sensing estimates obtain different estimates of global mean AOD. Glìß et al. (2020) also highlight the considerable diversity in the simulated contribution of various aerosol types to total AOD. However, models simulate regional trends in AODs that agree well, when expressed as percentage change, with ground- (**Glìß et al., 2020; Mortier et al., 2020**) and satellite-based (Cherian and Quaas, 2020a; **Glìß et al., 2020**) observations. AOD trends simulated by CMIP6 models are more consistent with satellite-derived trends than CMIP5 models for several subregions, thanks to improved emission estimates (Cherian and Quaas, 2020b)."*
Mortier, A. et al., 2020: Evaluation of climate model aerosol trends with ground-based observations over the last 2 39 decades – an AeroCom and CMIP6 analysis. Atmospheric Chemistry and Physics, 20(21), 13355–13378, 40 doi:10.5194/acp-20-13355-2020. **(incl. GAW and AERONET stations that are also ACTRIS stations)** Glìß, J. et al., 2020*: Multi-model evaluation of aerosol optical properties in the AeroCom phase III Control experiment, using ground and space based columnar observations from AERONET, MODIS, AATSR and a merged satellite product as well as surface in-situ observations from GAW. *Atmos. Chem. Phys. Discuss., 2020*, 1–62, doi:10.5194/acp-2019-1214. **(GAW and AERONET stations are also ACTRIS stations)** **Should be: Glìß, J. et al., 2021: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations. Atmospheric Chemistry and Physics, **21(1)**, 87–128, doi:10.5194/acp-21-87-2021.*
Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances; 6.3.5.1 Sulphate (SO_4^{2-}):
*"Global and regional models qualitatively reproduce observed trends over North America and Europe for the period 1990-2015 for which emission changes are generally well quantified (Aas et al., 2019; **Mortier et al., 2020**), building confidence in the relationship between emissions, concentration, deposition and radiative forcing derived from these models. Though, the models seem to systematically underestimate sulphate (Bian et al., 2017; Lund et al., 2018a) and AOD (Lund et al., 2018a; **Glìß et al., 2020**), and there are quite large differences in the models' distribution of the concentration fields of sulphate driven by differences in the representation of photochemical production and sinks of aerosols. One global model study also highlighted biases in simulated sulphate trends over the 2001-2015 period over eastern China due to uncertainties in the CEDS anthropogenic SO2 emissions trends (Paulot et al., 2018)."*

Mortier, A. et al., 2020: Evaluation of climate model aerosol trends with ground-based observations over the last 2 39 decades – an AeroCom and CMIP6 analysis. Atmospheric Chemistry and Physics, 20(21), 13355–13378, 40 doi:10.5194/acp-20-13355-2020. **(incl. GAW and AERONET stations that are also ACTRIS stations)** Gliß, J. et al., 2020*: Multi-model evaluation of aerosol optical properties in the AeroCom phase III Control experiment, using ground and space based columnar observations from AERONET, MODIS, AATSR and a merged satellite product as well as surface in-situ observations from GAW. *Atmos. Chem. Phys. Discuss., 2020*, 1–62, doi:10.5194/acp-2019-1214. **(GAW and AERONET stations are also ACTRIS stations)** **Should be: Gliß, J. et al., 2021: AeroCom phase III multi-model evaluation of the aerosol life cycle and optical properties using ground- and space-based remote sensing as well as surface in situ observations. Atmospheric Chemistry and Physics,* ***21(1)****, 87–128, doi:10.5194/acp-21-87-2021.*
Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances; 6.3.5.2 Ammonium (NH4+), and Nitrate Aerosols (NO3-):
*"Ammonium nitrate is semi-volatile, which results in complex spatial and temporal patterns in its concentrations (**Putaud et al., 2010**; Hand et al., 2012a; Zhang et al., 2012b) reflecting variations in its precursors, NH_3 and HNO_3, as well as SO_4^{2-}, non-volatile cations, temperature and relative humidity (Nenes et al., 2020). High relative humidity and low temperature as well as elevated fine particulate matter loading (Huang et al., 2014; **Petit et al., 2015**; Li et al., 2016; **Sandrini et al., 2016**) favour nitrate production. Measurements reveal high contribution of NO_3^- to surface PM2.5 (>30%) in regions with elevated regional NO_x and NH_3 emissions, such as the Paris area (**Beekmann et al., 2015**; **Zhang et al., 2019**), northern Italy (Masiol et al., 2015; **Ricciardelli et al., 2017**), Salt Lake City (Kuprov et al., 2014; Franchin et al., 2018), the North China Plains (Guo et al., 2014; Chen et al., 2016), and New Delhi (Pant et al., 2015)."*
Beekmann, M. et al., 2015: In situ, satellite measurement and model evidence on the dominant regional contribution to fine particulate matter levels in the Paris megacity. *Atmospheric Chemistry and Physics*, **15**, 9577–9591, doi:10.5194/acp-15-9577-2015. **(ACTRIS station SIRTA, France)** Petit, J.-E. et al., 2015: Two years of near real-time chemical composition of submicron aerosols in the region of Paris using an Aerosol Chemical Speciation Monitor (ACSM) and a multi-wavelength Aethalometer. *Atmospheric Chemistry and Physics*, **15(6)**, 2985–3005, doi:10.5194/acp-15-2985-2015. **(ACTRIS station SIRTA, France)** Putaud, J.-P. et al., 2010: A European aerosol phenomenology – 3: Physical and chemical characteristics of particulate matter from 60 rural, urban, and kerbside sites across Europe. *Atmospheric Environment*, **44(10)**, 1308–1320, doi:10.1016/j.atmosenv.2009.12.011. **(includes ACTRIS stations)** Ricciardelli, I. et al., 2017: A three-year investigation of daily PM2.5 main chemical components in four sites: the routine measurement program of the Supersito Project (Po Valley, Italy). *Atmospheric Environment*, **152**, 418–430, doi:10.1016/j.atmosenv.2016.12.052. **(Po Valley, Italy, ACTRIS site)** Sandrini, S. et al., 2016: Size-resolved aerosol composition at an urban and a rural site in the Po Valley in summertime: implications for secondary aerosol formation. *Atmospheric Chemistry and Physics*,

16(17), 10879–10897, doi:10.5194/acp-16-10879-2016. **(ACTRIS site Mt. Cimone, Po Valley observatory, Italy)**

Zhang, Y. et al., 2019: Six-year source apportionment of submicron organic aerosols from near-continuous highly time resolved measurements at SIRTA (Paris area, France). *Atmospheric Chemistry and Physics*, **19(23)**, 14755–14776, doi:10.5194/acp-19-14755-2019. **(ACTRIS station SIRTA, France)**

Chapter 6. Short-lived climate forcers, 6.3 Evolution of Atmospheric SLCF abundances; 6.3.5.3 Carbonaceous Aerosols:

*"Carbonaceous aerosols receive attention in the scientific and policy arena due to their radiative forcing, and their sizeable contribution to PM in an air quality context (Rogelj et al., 2014b; Harmsen et al., 2015; Shindell et al., 2016; Haines et al., 2017a; Myhre et al., 2017). BC exerts a positive ERF, but the ERF of carbonaceous aerosol as a whole is negative (Bond et al., 2013; Thornhill et al., 2021b). On average, carbonaceous aerosols accounts for 50 to 70% of PM with diameter lower than 1 µm in polluted and pristine areas (**Zhang et al., 2007**; Carslaw et al., 2010; Andreae et al., 2015; Monteiro dos Santos et al., 2016; Chen et al., 2017).*

*An extensive review on BC (Bond et al., 2013) discussed limitations in inferring its atmospheric abundance and highlighted inconsistencies between different terminology and related measurement techniques (**Petzold et al., 2013**; Sharma et al., 2017). Due to a lack of global observations, AR5 only reported declining total carbonaceous aerosol trends from USA and declining BC trend from the Arctic based on data available up to 2008. Since AR5, the number of observation sites has grown worldwide (see also Figure 6.7) but datasets suitable for global trend analyses remain limited (Reddington et al., 2017; **Laj et al., 2020**)."*

*"Lifetimes in models are estimated to 5.5 days ±35% for BC and 6.0 days ±29% for OA (median ± 1 standard deviation) according to an ensemble of 14 models (Gliß et al., 2021). Disagreement in simulated lifetime leads to horizontal and vertical variations in predicted carbonaceous aerosol concentrations, with implications for radiative forcing (Lund et al., 2018b) (Samset et al., 2013). Airborne campaigns have provided valuable vertical profile measurements of carbonaceous aerosol concentrations (Schwarz et al., 19 2013; **Freney et al., 2018**; Hodgson et al., 2018; Morgan et al., 2019; Schulz et al., 2019; Zhao et al., 2019a). Compared to those measurements, models tend to transport BC too high in the atmosphere, suggesting that lifetimes are not larger than 5.5 days (Samset et al., 2013; Lund et al., 2018b). Newly developed size-dependent wet scavenging parameterisation for BC (Taylor et al., 2014; Schroder et al., 2015; Ohata et al., 2016; Zhang et al., 2017a; Ding et al., 2019; Moteki et al., 2019; **Motos et al., 2019**) may lead to decreased BC lifetimes and improve agreement with observed vertical profiles."*

***"Table 6.6:** Summary of the regional carbonaceous aerosol trends at background observation sites." [includes **Kutzner et al., 2018; Querol et al., 2013**]*

Freney, E. et al., 2018: Aerosol composition and the contribution of SOA formation over Mediterranean forests. *Atmospheric Chemistry and Physics,* 18, 7041–7056, doi: 10.5194/acp-18-7041-2018, 2018. **(uses ACTRIS instrumentation)**

Kutzner, R.D. et al., 2018: Long-term monitoring of black carbon across Germany. Atmospheric Environment, 185, 41–52, doi:10.1016/j.atmosenv.2018.04.039. **(includes ACTRIS sites?)**

Laj, P. et al., 2020: A global analysis of climate-relevant aerosol properties retrieved from the network of Global Atmosphere Watch (GAW) near-surface observatories. *Atmospheric Measurement Techniques*, **13(8)**, 4353–4392, doi:10.5194/amt-13-4353-2020. **(some of the GAW stations are also ACTRIS sites)**

Motos, G. et al., 2019: Cloud droplet activation properties and scavenged fraction of black carbon in liquid-phase clouds at the high-alpine research station Jungfraujoch (3580ma.s.l.). *Atmospheric Chemistry and Physics*, doi:10.5194/acp-19-3833-2019. **(ACTRIS station Jungfraujoch, Switzerland)**

Petzold, A. et al., 2013: Recommendations for reporting black carbon measurements. *Atmospheric Chemistry and Physics*, **13(16)**, 8365–8379, doi:10.5194/acp-13-8365-2013. **(recommendation from the ACTRIS community)**

Querol, X. et al., 2013: Variability of carbonaceous aerosols in remote, rural, urban and industrial environments in Spain: Implications for air quality policy. *Atmospheric Chemistry and Physics*, **13(13)**, 6185–6206, doi:10.5194/acp-13-6185-2013. **(includes the Spanish ACTRIS sites)**

Zhang, Q. et al., 2007: Ubiquity and dominance of oxygenated species in organic aerosols in anthropogenically influenced Northern Hemisphere midlatitudes. *Geophysical Research Letters*, doi:10.1029/2007gl029979. **(ACTRIS sites involved: Hyytiälä, Finland; Hohenpeissenberg, Germany; Jungfraujoch, Switzerland)**

Chapter 6. Short-lived climate forcers, 6.4 SLCF radiative forcing and climate effects:

*"In advance of CMIP6, representations of aerosol processes and aerosol-cloud interactions in ESMs have generally become more comprehensive (Glíß et al., 2021; Meehl et al., 2020; Thornhill et al., 2021b; see also Section 1.5), with enhanced links to aerosol emissions and gas-phase chemistry. Many CMIP6 models (see Annex II Table AII.5) now simulate aerosol number size distribution, in addition to mass distribution, which is a prerequisite for accurately simulating number concentrations of cloud condensation nuclei (CCN) (Bellouin et al., 2013) while some CMIP6 models use prescribed aerosol optical properties to constrain aerosol forcing (e.g., Stevens et al., 2017). Hence, the range of complexity in aerosol modeling noted in CMIP5 is still present in the CMIP6 ensemble. Although simulated CCN have been compared to surface (**Fanourgakis et al., 2019**) and aircraft (Reddington et al., 2017) measurements, with mixed results, the lack of global coverage limits confidence in the evaluations."*

Fanourgakis, G.S. et al., 2019: Evaluation of global simulations of aerosol particle and cloud condensation nuclei number, with implications for cloud droplet formation. *Atmospheric Chemistry and Physics*, **19(13)**, 8591–8617, doi:10.5194/acp-19-8591-2019. **(uses data from 8 ACTRIS stations)**

Chapter 6. Short-lived climate forcers, 6.4 SLCF radiative forcing and climate effects; 6.4.5 Non-CO2 biogeochemical feedbacks:

*"**Climate-BVOC feedback:** BVOCs, such as isoprene and terpenes, are produced by land vegetation and marine plankton (Section 6.2.1.2). Once in the atmosphere, BVOCs and their oxidation products lead to the formation of secondary organic aerosols (SOA) exerting a negative forcing, and increased ozone concentrations and methane lifetime exerting a positive forcing. BVOC emissions are suggested to lead to a climate feedback in part because of their strong temperature dependence observed under present-day conditions (**Kulmala et al., 2004**; Arneth et al., 2010a). Their response to future changes in climate and CO_2 levels remains uncertain (see Section 6.2.2.3. Estimates of the climate-BVOC feedback*

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*parameter are typically based on global models which vary in their level of complexity of emissions parameterization, BVOC speciation, the mechanism of SOA formation and the interaction with ozone chemistry (Thornhill et al., 2021a). Since AR5, observational studies (**Paasonen et al. 2013**) and models (**Scott et al. 2018**) estimate the feedback due to biogenic SOA (via changes in BVOC emissions) to be in the range of about –0.06 to -0.01 W m^{-2} °C^{-1}. The assessed central estimate of the climate-BVOC feedback parameter based on the AerChemMIP ensemble suggests that climate-induced increases in SOA from BVOCs will lead to a strong cooling effect that will outweigh the warming from increased ozone and methane lifetime, however the uncertainty is large (Thornhill et al., 2021a).”*
Kulmala, M. et al., 2004: A new feedback mechanism linking forests, aerosols, and climate. *Atmospheric Chemistry and Physics*, **4(2)**, 557–562, doi:10.5194/acp-4-557-2004. **(Hyytiälä. Finland ACTRIS site)** Paasonen, P. et al., 2013: Warming-induced increase in aerosol number concentration likely to moderate climate change. *Nature Geoscience*, **6(6)**, 438–442, doi:10.1038/ngeo1800. **(ACTRIS sites Hyytiälä, Finland, Värriö, Finland and Melpitz Germany included)** Scott, C.E. et al., 2018: Substantial large-scale feedbacks between natural aerosols and climate. Nature Geoscience, 11(1), 44–48, doi:10.1038/s41561-017-0020-5. **(Multiple ACTRIS sites, e.g. Hyytiala (SMEAR II), Värrio (SMEAR I), Melpitz, Hohenpeissenberg)**
Chapter 6. Short-lived climate forcers, 6.6 Air Quality and Climate response to SLCF mitigation; 6.6.2.3.5 Source attribution of regional air pollution:
*“Natural sources contribute more than 50% to surface ozone in all regions except South Asia and South East Asia. South Asia, East Asia and the Middle East experience the highest 1 surface ozone levels of all regions. For ozone, the anthropogenic sectoral attribution is more uniform across regions than for PM2.5, except for South and Southeast Asia where land transportation plays are larger role and East Asia with most significant contribution from energy and industry. Land transportation and energy are the most important contributors to ozone across many of the regions, with smaller contributions from agriculture, biomass burning, waste management and industry. Open biomass burning is not a major contributor to surface ozone, except for Africa, Latin America and South East Asia where its contribution is estimated at about 5-10% of anthropogenic sources. Relative importance of natural and anthropogenic emission sources on surface ozone have been assessed in several studies (Uherek et al., 2010; **Zare et al., 2014**; Mertens et al., 2020; Unger et al., 2020) and the results are comparable with the estimates of the TM5-FASST used here.”*
Zare, A. et al., 2014: Quantifying the contributions of natural emissions to ozone and total fine PM concentrations in the Northern Hemisphere. *Atmospheric Chemistry and Physics*, **14(6)**, 2735–2756, doi:10.5194/acp-14-2735-2014. **(ACTRIS sites involved: Hyytiälä, Finland; Vielsalm, Belgium)**
Chapter 6. Short-lived climate forcers, 6.6 Air Quality and Climate response to SLCF mitigation:
*“**BOX 6.2: SLCF Mitigation and Sustainable Development Goals (SDG) opportunities** However, the design of suitable policies addressing these SDGs can be difficult because of the complexity linking emissions to impacts on human health, ecosystem, equity, infrastructure, and costs. Beyond the fact that several species are co-emitted, interlinkage between species, for example through atmospheric chemistry, can weaken the benefit of emissions reduction efforts. An illustration lies in the recent (2013-2017) reduction of aerosols over China (Silver et al., 2018; Zheng et al., 2018b) resulting*

from the strategy to improve air quality ("Clean Air Action"), has successfully reduced the level of PM2.5 but has led to a concurrent increase in surface ozone, partly due to declining heterogeneous interactions of O3 precursors with aerosols (Li et al., 2019a; Yu et al., 2019). This side effect on ozone has been addressed since then by amending the legislation to target NMVOC sources, especially solvent use. Complex interactions between anthropogenic and biogenic vapours are also at play and reduction of certain SLCFs could possibly promote new particle formation from organic vapours (e.g., ***Lehtipalo et al., 2018****)."*
Lehtipalo, K. et al., 2018: Multicomponent new particle formation from sulfuric acid, ammonia, and biogenic vapors. *Science Advances*, **4(12)**, eaau5363, doi:10.1126/sciadv.aau5363. **(ACTRIS site SMEAR II, Hyytiälä, Finland)**

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