Title	Report on long-term strategy of VA activities and the new services in ATMO-ACCESS, taking into account the tools developed in WP5 and their best usage for science, management and outreach
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ATMO ACCESS
Access to Atmospheric Research Facilities

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Introduction

This report outlines a long-term strategy for Virtual Access (VA) services developed within the ATMO-ACCESS project, incorporating innovative tools and methodologies from Work Package 5 (WP5). The feedback reports D10.1 First report with feedback from users and statistics on use of the services and D10.2 Second report with feedback from users and statistics on use of the services, as well as insights into finances, outreach, and scientific impact from *D10.4 Report on the suitability of the different services modalities taking into account finances, outreach and scientific impact* are used as the essential background material to develop this strategy.

The focus is on ensuring the sustainability, integration, and accessibility of the services developed. By aligning these services with research infrastructure (RI) needs and financial models, the strategy aims to support ongoing collaboration, data sharing, and scientific advancements in atmospheric research. Each service will have a long-term strategy recommendation at first, followed by the explanation and experiences on which the recommendations are based.

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Summary of compiled statistics and feedback to the VA services

The services within ATMO-ACCESS, accessed through the Virtual Access (VA) Portal, have demonstrated significant engagement and benefit for users. The VA portal has served as the central gateway to these services. The numbers below are for the period release of the VA services (March – June 2023) until the ATMO-ACCESS Final meeting (March 2025). The Homeless Data Portal has seen substantial activity with 24 data curation requests and 1412 datasets curated with Persistent Identifiers (PIDs) such as, for example, Digital Object Identifiers (DOIs) over the period March 2023 to March 2025. The Time Series Analysis Service has attracted 564 unique visits and processed 3,305 dataset API requests during the same period. The trajectory and footprint analysis tools for ACTRIS, ICOS, and IAGOS also exhibit strong demand. The ACTRIS footprint analysis service recorded 1,565 visits and processed 104 requests for model runs. The ICOS footprint viewer recorded a total of 83 individual users who viewed 2,344 footprint animations in the period of March to April 2025. From the start until March 2025, the ICOS footprint service facilitated 1,116 model runs (total 1 875 016 individual footprints) and 432 download requests (total 1 618 560 individual footprints). Furthermore, the IAGOS footprint analysis service logged 533 unique users and displayed 9,148 footprint requests, reflecting its role in analyzing tropospheric vertical profiles. These numbers are not directly comparable, as each VA service entails different types of processing and work.

Overall, the use of these services highlights their essential role in supporting atmospheric research and data management. However, engaging users to provide feedback has proven difficult, with the amount of feedback received being limited compared to the effort invested in collecting it. This is partly due to the nature of Virtual Access services, which are often used without direct interaction with service providers. The most useful insights were typically gathered through direct conversations at meetings rather than through online forms. While user feedback that was received generally indicates satisfaction, the strong usage statistics across all services ultimately provide the clearest evidence of their value to the scientific community, reinforcing the importance of VA services.

Summary of finances, outreach, and scientific impact

A comprehensive assessment of the suitability and sustainability of the ATMO-ACCESS Virtual Access (VA) services has been conducted, with a specific focus on financial models and scientific impact. Each service is analyzed in terms of operational costs, outreach activities, and scientific value, with service-specific financial models tailored to their structure and mode of access.

For services like the Homeless Data Portal and FLEXPART requests in the ACTRIS footprint analysis, cost models typically include both fixed and variable components. Fixed costs account

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for core operations such as portal maintenance and user support, while variable costs depend on the scope and complexity of user requests (e.g., number of datasets, new stations, or novel model runs). In contrast, services based on pre-generated products or API access —such as Time Series Analysis and the IAGOS footprint service —rely on fixed annual costs, often divided into categories for baseline operation and user-driven developments based on feedback. The ICOS footprint service differentiates between costs for maintaining existing products, producing new footprints, and handling custom user requests. The MOOC has a production cost related to course development, but once completed and tested, maintenance costs remain low. However, as MOOCs typically require updates after 3, 5 or 10 years, long-term planning is essential.

Despite their relatively recent deployment, the services are already demonstrating strong scientific impact. The Homeless Data Portal has curated over 1,400 datasets, following the FAIR principles under CC-BY 4.0 licensing, and is actively supporting projects like RI-URBANS. The ACTRIS footprint service has contributed to several peer-reviewed publications and is used both for NASA field campaign planning and for operational mineral dust forecasts provided to the CHOPIN campaign within the CleanCloud project. The ICOS STILT service plays a key role in the CORSO project, enabling automatic footprint forecasting for radiocarbon flask sampling. The IAGOS footprint tools have contributed to one peer-reviewed publication and have supported the CAMS project by enhancing model evaluation using vertical profile data. The Time Series Analysis service has enabled cross-RI data integration and supported initiatives like the Tropospheric Ozone Assessment Report (TOAR), streamlining complex atmospheric analyses. Finally, the MOOC has reached over 800 participants worldwide, many with advanced academic backgrounds, underscoring its educational and outreach success.

In summary, the deliverable demonstrates the growing scientific relevance of the VA services and outlines cost models that support their long-term sustainability. These insights provide a foundation for strategic planning and ensure that the services remain impactful and financially viable in the future.

Long-term strategy of VA activities from ATMO-ACCESS

The long-term strategy for VA activities aims to ensure sustainability for the tools developed in WP5 to support ongoing collaboration and advancements in atmospheric research.

General aspects, experiences gained and considerations

All VA services require a stable host architecture with long-term perspectives and ongoing maintenance, ideally linked to a sustainably funded web application. Currently, the services are accessible through a common entry point on the ATMO-ACCESS Virtual Access platform, but

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the services themselves mostly rely also on RI-specific web infrastructure. Maintaining separate websites entails costs and staff time not covered beyond the lifetime of ATMO-ACCESS. Therefore, ***a key recommendation*** is to integrate each VA service into one or more RI data portals, leveraging existing infrastructure to ensure long-term support. The VA portal itself can remain online with minimal funding if administrative burdens (e.g. user logins) are removed.

The feedback gathered throughout the project highlights that user engagement and feedback collection for VA services can be challenging. The nature of Virtual Access—often fully automated or asynchronous—means many users do not interact directly with service providers. Consequently, collecting meaningful feedback through regular forms or e-mails has proven time-consuming. The most useful insights were typically gathered through direct contact with users during meetings, workshops, conferences, user presentations, and project advertisements. Our experience indicates that users generally refrain from providing feedback when they are satisfied, and feedback is mainly given when users have specific remarks or requests for improvement. Therefore, for future services, embedding simple feedback tools, such as short multiple-choice forms with only one open-ended question, could improve usability without overwhelming users.

A general recommendation for all VA services, also in future collaborative projects such as IRISCC, is to implement basic user tracking, such as IP address logging or visit counters. These can help generate consistent usage statistics (visits, downloads, and requests) without requiring user registration. It is urged to explore possible solutions for linking the usage of VA services to specific research projects, particularly when such projects fund the service provision, even though this is inherently challenging due to the open-access nature of Virtual Access, which must remain freely and anonymously available to all users without pre-selection, in accordance with EU funding conditions. Each VA service should implement additional tracking tailored to the nature of the service—for example, tracking downloads of available products, logging model requests that result in new product generation, or monitoring API usage. Uniform display and interpretation of such statistics across services will improve reporting and comparability.

Finally, several services reported that large or resource-intensive requests often come at the last minute—especially in connection with TNA campaigns. A strategic improvement would be to encourage, or even instruct users in the TNA application phase, to submit requests earlier in the TA project lifecycle. Cost estimates should be made available so that project proponents can plan ahead and consider including data service costs in their research project budgets. This approach will support both better planning and the financial sustainability of the services, especially for those operating outside core project funding.

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Looking ahead, it is important to distinguish between services that benefit from cross-RI collaboration and those that are best sustained within individual research infrastructures. The Time Series Analysis service should remain a collaborative effort between ACTRIS, ICOS, and IAGOS, as its main purpose is to enable users to access and analyze data across multiple RIs. Its success depends on continued integration with RI APIs and coordinated data availability. In contrast, services such as the Homeless Data Portal and the various trajectory and footprint analysis tools are best integrated into RI-specific infrastructures. For the Homeless Data Portal, nearly all requests so far have been RI-specific and no clear demand for cross-RI dataset collections has been observed. However, it may be worth considering that this could change in the future, given the EU Commission's increasing emphasis on cross-disciplinary and multi-RI research initiatives.

Moreover, these services depend on RI-specific workflows and cost structures, making full harmonization across RIs unnecessarily complex and resource-intensive. Each RI should therefore maintain its version of these services, potentially offering lightweight coordination features without merging them into a unified platform.

Retaining the ATMO-ACCESS tag or branding ensures continuity and project recognition, while simplifying access routing to RI-specific platforms.

The Homeless Data Portal - aspects, experiences and recommendation

Our recommendation is to integrate a version of the Homeless Data Portal (HDP) into each RI's data center portal, where it can be operated and maintained as part of the RI's regular activities. Each RI-specific HDP service should be tailored to its community's needs, while maintaining FAIR principles and enabling long-term dataset visibility. In cases where a dataset may involve more than one RI, the service should allow users to indicate this, enabling coordination between curators. Collection DOIs linking related datasets across RIs can serve as a practical and lightweight form of cross-RI coordination.

Depending on the nature and extent of the request, the RI may choose to cover the cost through its operational budget or request that users include data curation costs in their project proposals, using the HDP financial model as a guide.

The Homeless Data Portal (HDP) is a service designed to manage and share datasets that fall outside the scope of established RI data workflows—typically originating from short-term projects, campaigns, or TNAs. It ensures long-term storage, FAIR compliance, and improved visibility of these datasets through DOI assignment and RI-level curation. From March 2023 to March 2024, the portal received 24 data curation requests (22 to ACTRIS DC, 2 to ICOS CP) and

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curated a total of 1,412 datasets (1410 to ACTRIS DC, 2 to ICOS CP), all assigned Persistent Identifiers (PIDs).

Requests have been almost entirely RI-specific, typically involving single stations or instruments. No substantial demand for cross-RI collections has emerged, and financial models vary between RIs. Therefore, it is recommended that each RI integrates and maintains its own version of the HDP within its data center. This enables tailored support while maintaining shared standards for accessibility and quality.

To improve sustainability, users should be encouraged to submit data requests early in project lifecycles, allowing better resource planning and the inclusion of curation costs in proposals. ICOS, for instance, already handles such workflows through existing project agreements.

Occasional cross-RI cases may arise; thus, each HDP instance should allow users to indicate multi-RI relevance, enabling curators to coordinate directly through the well-established collaboration in ATMO-ACCESS, ENVRI-FAIR and other successor projects. Full harmonization is not advised due to structural and financial differences across RIs, and large differences in the interest in this service between the RIs. However, light coordination remains valuable. The use of collection DOIs that link related datasets across RIs is one example of such coordination, supporting discoverability without requiring a unified infrastructure.

Finally, some requests have involved higher-level or interdisciplinary products that fall outside current RI scopes—such as model–observation combinations. While these cannot be supported at present, they reveal a strategic opportunity for future development, potentially through new platforms or workflows in upcoming projects.

Trajectory and footprint analysis tools - aspects, experiences and recommendation

Our recommendation is to operate and maintain the trajectory and footprint services within each RI by fully integrating them into RI-specific data portals, ensuring continued accessibility, sustainability, and support for the research community.

The cost of these services should be covered through a combination of RI operational funding for standard products and transparent cost-recovery models for custom or resource-intensive requests.

The trajectory and footprint analysis tools developed within ATMO-ACCESS have proven to be essential for supporting atmospheric research. These services enable source attribution, transport modeling, and visualization of atmospheric composition data, and have been widely used across different scientific communities and applications.

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As these tools are closely aligned with the structure and focus of individual Research Infrastructures (RIs), our recommendation is to fully integrate each service into its respective RI data portal. This ensures continued accessibility, technical support, and alignment with community-specific needs. There are few, if any, benefits to keeping this as a cross-RI service, and it will also be very costly to maintain.

The cost structure should reflect the nature of the service provided. Routine or standardized model outputs may be supported through RI operational budgets, while customized or high-demand requests should follow the cost calculation frameworks developed during the project.

Greenhouse gases - aspects, experiences and recommendation

The ICOS STILT Footprint tools (viewer and job starter) are services to allow users to view atmospheric backward footprints and demand online for calculation of new footprints for user defined and existing observations stations and 3D locations within the European domain. Footprints are calculated using the STILT model and are based on ERA5 analyzed wind fields at a resolution of 1 degree and the footprints returned are 3-hourly at a resolution of 0.1*0.05 degree. Next to the footprint information the STILT model also calculates a forecast of the expected concentration of CO2 or CH4 at the receptor point, based on a set of high-resolution emission databases that describe the emissions of several source categories on a high temporal and spatial resolution.

Both services were already available to the users from the ICOS Carbon Portal before the ATMO ACCESS project in a rudimentary form and had already been used to generate quite a lot of footprints. For the project, the services were further developed, refined, extended to CH4, linked to the VA portal, the VA usage API and the AERIS single sign on. Most important improvements besides the extension to CH4 (and the corresponding additional calculations for existing footprint of CH4 modelling concentrations), were the provisioning and packaging of footprint results for download, better linking to more observed observational datasets for comparison with modelled concentrations, the improved help functionality and numerous improvements in the user interface to avoid clutter in the map interface due to the enormous amount of receptor point that can be chosen.

The sustainable strategy is again to integrate the service into the ICOS data portal, ensuring continued accessibility and support for the research community. This service will be also be used in the framework of the IRISCC project and will be accessible during the duration of the project (until Sep 2028) because, after extension to CO, it will be part of a further integrated service with the other RIs on demonstrators dedicated to wild fires and detection of drought effects on the carbon cycle.

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Tropospheric vertical gradients - aspects, experiences and recommendation

The IAGOS footprint viewer is a service for the visualization of footprints and origin of the air masses sampled by IAGOS (characterized by carbon monoxide observations). It is based on pre-generated Level 4 products calculated from the FLEXPART model coupled to different emissions inventories for biomass burning and anthropogenic sources, defining thus the "source-receptor link" model called SOFT-IO (Sauvage et al., 2017). The maintenance of this model launch is time and resources (human and computing) consuming because it includes ECMWF meteorological fields, automated extraction and access to emission inventories. The Maintenance of the service also implies being reactive enough to provide it on a near-real-time basis, just like the IAGOS observations. Making the service always useful and scientifically robust also requires regular maintenance to adapt the model to the "best" meteorological fields and emissions inventories. The support to users and/or answering requests on demand are also to be counted as time-consuming tasks.

The financial model presented in D10.4 shows the annual cost necessary to maintain the service. Without a dedicated budget, the service could not be sustainable. A web form allows users to provide feedback on the service. Maintenance costs include corrections or implementation of new features based on this feedback.

The sustainable strategy is to fully integrate the service into the IAGOS data portal, ensuring continued accessibility and support for the research community. This service will be used in the framework of the IRISCC project and will be accessible for the duration of the project (until Sep 2028) because it will be part of a further integrated service with the other RIs on a demonstrator dedicated to Wildfires.

Footprint analysis, and aerosol and trace gas distribution and source analysis - aspects, experiences and recommendation

The footprint analysis tool and aerosol/trace gas distribution services developed under ATMO-ACCESS have proven highly valuable, offering both retrospective and near-real-time products that support a wide range of scientific applications. These services include long-term model runs for black carbon, dust, and microplastics (from 2010 – present), as well as near real-time forecasts with high time resolution of 3 hours. They have been widely used by the research community, contributing to several peer-reviewed publications and enabling advanced source attribution studies for atmospheric constituents.

As part of the long-term strategy, the service will be fully integrated into the ACTRIS Data Portal, with dedicated landing pages and inclusion in both facility pages and data search tools to ensure visibility, discoverability, and continued accessibility. Model run requests—both

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standard and custom—will continue to be supported. Standardized black carbon model runs for ACTRIS facilities are recommended to be covered by RI operational budgets, recognizing their regular use and scientific relevance. Customized requests, including new product types, long time series, or additional variables, will be calculated using the detailed financial model developed in ATMO-ACCESS. NILU may waive or reduce costs for such requests when aligned with scientific collaborations or EU-funded projects, supporting knowledge exchange and capacity building.

In addition, for large or resource-intensive requests, early engagement with users is essential, ideally as part of proposal planning or project design. This approach ensures that resource use is transparent and justifiable, and that outputs are fit for purpose and can be appropriately referenced in resulting scientific publications.

Looking ahead, the service will continue to operate as part of the IRISCC project until at least September 2028, contributing as a VA service in the Catalogue of Services and to an integrated demonstrator focused on wildfire-related impacts across RIs. With its flexibility, scientific track record, and high user interest, the footprint and source analysis service represents a core long-term capability within ACTRIS and a model for future RI-aligned service delivery.

Time Series Analysis

Our recommendation is to fully integrate the Time Series Analysis service into the IAGOS data portal and ensure its sustainability through dedicated RI support. Continued access depends on the availability and stability of web APIs from ACTRIS, ICOS, and IAGOS, which must remain a priority.

The Time Series Analysis is a service for discovering, selecting and analyzing datasets from ACTRIS, IAGOS and ICOS RIs. The searching and retrieving of the datasets is based on web APIs hosted by each RI. Datasets used for IAGOS are Level 3 products (average profiles) generated specifically for this service in order to provide data at station resolution (like ACTRIS and ICOS).

The financial model presented in D10.4 shows the annual cost necessary to maintain the service. Without a dedicated budget, the service could not be sustainable. A web form allows users to provide feedback on the service. Maintenance costs include corrections or implementation of new features based on this feedback.

The service is highly dependent on the availability of the RI's access web APIs. Ensuring the sustainability of those APIs must be a priority for the RIs since their main goal is to provide access to their data. However, the interface between the service and the APIs is based on

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normalized data formats. It is essential that the formats are maintained by the RIs otherwise their data will not be available anymore in the service.

The sustainable strategy is to fully integrate it into the IAGOS portal, ensuring continued accessibility and support for the research community. This service will be used in the framework of the IRISCC project and will be accessible for the duration of the project (until Sep 2028) because it will be part of a further integrated service with the other RIs on a demonstrator dedicated to the Impact of Heat waves on air quality issues. It is also complementary to the First Release services of IRISCC (climatologies and anomalies of ECVs).

To improve the user access and experience utilizing the WP5 tools, a tutorial video part of WP4 has been developed: "A Step-by-Step Tutorial Video for Time Series Analysis in ATMO-ACCESS. This tutorial will also be implemented into the MOOC 2nd edition, encouraging and advertising even further the Time Series Analysis tool and the use of the RI datasets.

Massive Open Online Course (MOOC)

Our recommendation is to keep the MOOC accessible in a self-paced format as long as the content remains relevant, and to conduct a review after 2–3 years to evaluate the need for updates.

The ATMO-ACCESS MOOC, *"Atmospheric Research Infrastructures: Sharing the Future of Our Atmosphere"*, has proven to be a valuable outreach and training tool. Launched in early 2025, it attracted over 800 participants from 74 countries for its first edition, many with advanced academic backgrounds (more than 450 participants from 63 countries are currently enrolled for the 2nd edition, which started on May 12th, 2025). The course successfully raised awareness of ACTRIS, ICOS, and IAGOS and highlighted their role in addressing climate and air quality challenges.

The MOOC is low-cost to maintain, particularly through the FUN platform, and can remain open in a self-paced format with minimal effort. However, as course content typically becomes outdated within 5–10 years, a review is recommended after 2–3 years to assess whether updates are needed.

The MOOC also provides a platform for integrating additional training materials, such as tutorial videos from WP4. It complements other knowledge-sharing efforts and should be kept accessible as long as the content remains relevant, with periodic updates planned to ensure continued impact.

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Conclusions

Deliverable D10.3 presents a long-term strategy for sustaining the Virtual Access (VA) services developed in ATMO-ACCESS, with recommendations based on user feedback, usage statistics, and financial and scientific evaluations. The strategy emphasizes integrating services such as the Homeless Data Portal and the trajectory and footprint tools into RI-specific data portals to ensure stability and alignment with user communities. Services with clear cross-RI relevance, such as the Time Series Analysis, should remain collaborative, as they rely on data and infrastructure from multiple RIs. Financial models tailored to each service support cost transparency and sustainability, with flexibility for research collaborations. The MOOC stands out as a valuable, low-cost outreach tool with global reach. To ensure long-term usability and impact of all the VA services, the report recommends consistent service tracking, early user engagement, and lightweight cross-RI coordination, such as through collection DOIs.

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