Deliverable 4.3: CARGO-ACT site distribution strategy

Authors: Lucia Mona, Fabrizio Marra, Ermann Ripepi, Ewan O'Connor, Jasper Lewis, Betsy Andrews, Markus Fiebig, Doina Nicolae, Alfred Wiedensohler, Martine De Mazière, Giri Prakash

Work package no	WP4
Deliverable no.	D4.3
Lead beneficiary	CNR
Deliverable type	X R (Document, report) ☐ DEC (Websites, patent filings, videos, etc.) ☐ OTHER: please specify .....
Dissemination level	X PU (public) ☐ CO (confidential, only for members of the Consortium, incl. Commission)
Estimated delivery date	M30
Actual delivery date	02/11/2026
Version	Final
Reviewed by	Sergio Moreno Valero
Accepted by	Ewan O'Connor
Comments	

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

Contents

1 Introduction 3
2 Current EU and US site distribution 3
3 Identification of observational gaps 7
3.1 Geographical coverage 7
3.1.1 Regional aspects 7
3.1.2 Global aspects 8
3.2 Data provision gaps 12
4 Potential strategies for filling the gaps 13
4.1 Deployment of mobile platforms 13
4.2 Integration of ground-based and satellite observations 14
5 Global perspective beyond the EU-US framework 14
6 References 16

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

1 Introduction

CARGO-ACT is not a network itself, but a project aimed at fostering cooperation, particularly between Europe and the United States, in the field of atmospheric observations. A number of existing observational networks have been identified (Mona et al., 2024). These networks provide varying levels of spatial and thematic coverage. Most of them have evolved over time based on the availability of resources, national priorities, institutional willingness, and local expertise, rather than through a coordinated design process specifically aimed at meeting scientific or societal needs in a harmonized manner. International initiatives such as the WMO Global Atmosphere Watch (GAW) have provided an overarching and coherent framework for connecting, integrating, and improving national and regional observing networks. CARGO-ACT poses itself within this broader context. Therefore, it is not appropriate to refer to a specific "CARGO-ACT site distribution". Instead, the project aims to assess the current distribution of observing capabilities, identify existing gaps, and propose strategies for improving the overall observational framework. The analysis of this deliverable will focus on the following aspects: current EU and US site distribution for CARGO-ACT relevant networks; identification of observational gaps; potential strategies for filling the gaps and global perspectives.

2 Current EU and US site distribution

The current distribution of observing sites in Europe and the United States is analysed according to the following main observation categories:

- Aerosol, clouds and trace gases in situ observations;
- Aerosol profiling observations;
- Cloud profiling observations;
- Trace gas profiling observations.

In the case of ACTRIS (Aerosol Clouds Trace Gases Research InfraStructure, https://actris.eu/facilities/national-facilities/overview) only permanent and fixed stations has been considered, while mobile platforms and atmospheric chambers are not here considered. For the US component, ARM (U.S. Department of Energy's Atmospheric Radiation Measurement, https://armgov.svcs.arm.gov), MPLNET (NASA Micro-Pulse Lidar Network, https://mplnet.gsfc.nasa.gov) and NFAN (NOAA Federated Aerosol Network, https://gml.noaa.gov/aero/net/) networks have been considered for aerosol and clouds profiling, aerosol profiles and in situ observations, respectively. ARM sites providing in situ measurements are also included in the in situ map. NDACC (Network for the Detection of Atmospheric Composition Change, https://www.ndacc.org and https://frm4doas.aeronomie.be/data) has been considered as international network for the trace gases profiling observations in addition to the corresponding ACTRIS component.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

Within ACTRIS, for each observational category only the national facilities hosting the corresponding component are included in the current analysis.

It is worthwhile to highlight here that in most cases these networks grew as a result of the interest, willingness and typically voluntary efforts of research groups that put resources in terms of equipment and human capital for collecting long term observations of 1 or more atmospheric constituents. Therefore, the geographical coverage is typically the combination of groups' choices and national/regional capacity to support them.

Figures 1 and 2 report the current geographical distribution of the observational sites for the 4 classes of atmospheric variables reported above.

For in situ observations, ACTRIS densely covers Europe, while NFAN focuses mainly in the US but it also touches all the continents as well as the extreme north and south of the globe. Aerosol remote sensing observations are currently performed in many sites in US and Europe thanks to MPLNET/ARM and ACTRIS, respectively. Some close by or coincident observational sites are available for aerosol profile in Europe. In addition, some observational sites are available in islands offshore of the African continent, in the Indian Ocean and across East Asia archipelagos. There is a similar distribution, although with less sites, for the cloud remote sensing networks,. For the reactive trace gases observational capability, NDACC has a relatively good number of sites. However, NDACC stations are located most often in remote location except for a few exceptions like Paris, Mexico City, and Uccle.: this means that urban environments, where the reactive trace urban gases are continuously released into the atmosphere in large quantities from concentrated anthropogenic sources, are less well covered.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

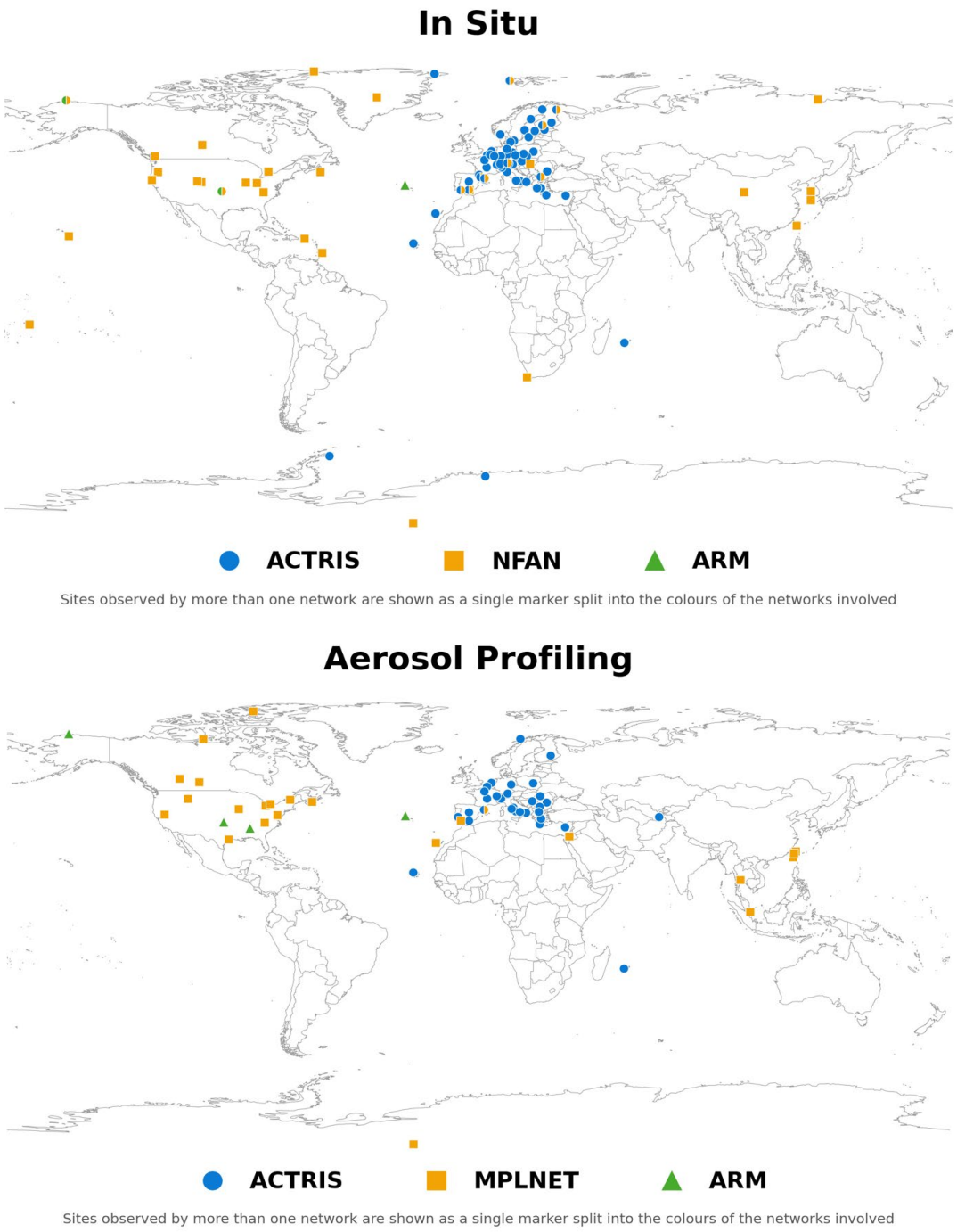


Figure 1. Geographical distribution of the observational sites of the CARGO-ACT participating networks for In Situ and for Aerosol Profiling measurements.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

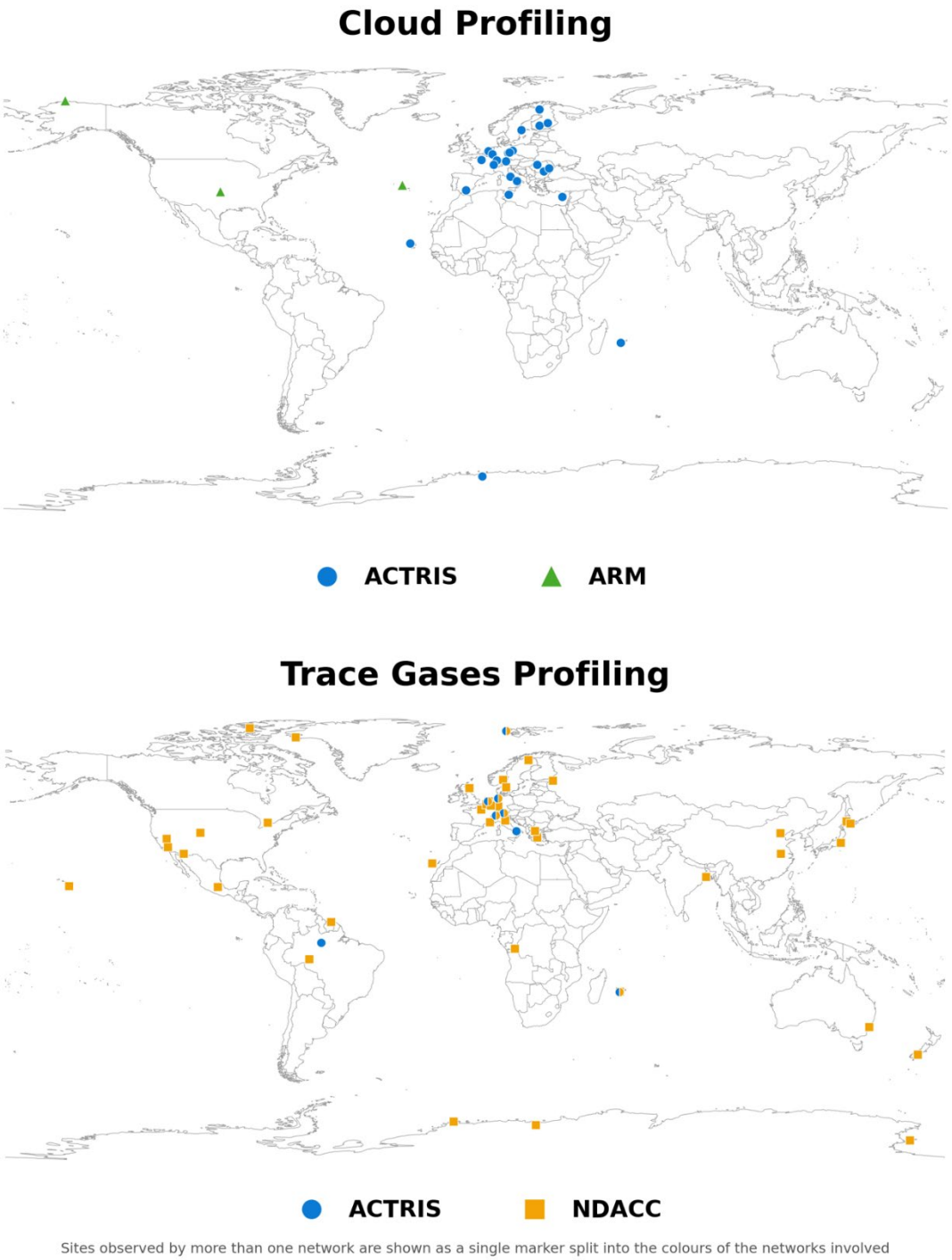


Figure 2. Geographical distribution of the observational sites of the CARGO-ACT participating networks for Clouds and Trace Gases Profiling measurements.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

3 Identification of observational gaps

3.1 Geographical coverage

3.1.1 Regional aspects

Although Europe and the United States are the two most densely represented regions in the networks considered, the maps reveal that high station numbers do not necessarily provide spatially uniform or thematically complete coverage. The maps indicate a higher concentration of sites across parts of Central, Western and Northern Europe, while eastern and south-eastern Europe, some peripheral Mediterranean areas and remote maritime sectors appear less consistently represented. This imbalance is particularly evident for cloud and trace-gas profiling, for which the number and geographical spread of sites are lower than for in situ aerosol observations and aerosol profiling. The trace-gas profiling map shows more evident gaps in Canada and in parts of the continental interior, and with limited co-location with the aerosol, cloud and in situ observational capabilities considered here. Even within the more densely instrumented European core, the four observational capabilities are not always co-located. This limits the number of supersites able to provide simultaneous, vertically resolved and surface-based observations of aerosols, clouds and trace gases under the same air mass and meteorological conditions.

In the United States, the combined contribution of ARM, MPLNET and NFAN provides valuable coverage, but the spatial pattern differs substantially among observational domains. In situ aerosol observations are more broadly distributed, whereas aerosol remote sensing and especially cloud remote-sensing capabilities are concentrated at a smaller number of stations. The maps also show limited trace-gas remote-sensing representation over the United States within the networks considered in this assessment. As a result, large areas remain without co-located multi-component observations, including parts of the western interior and other regions influenced by wildfire smoke, dust, urban emissions and long-range transport. The limited overlap among in situ, aerosol profiling, cloud profiling and trace-gas measurements constrains integrated process studies and the evaluation of satellite and model products across contrasting US environments.

Consequently, the principal EU-US gap is not simply the absence of observations, but the uneven distribution of integrated observational capacity. Priority should therefore be given to 1) strengthening underrepresented European and US regions, 2) improving continuity at existing long-term stations, and 3) increasing co-location or coordinated operation among complementary measurement systems. A more balanced transatlantic configuration would improve the characterization of regional gradients, facilitate consistent comparisons between European and US environments, and strengthen support for satellite validation, model evaluation and studies of aerosol-cloud-trace-gas interactions.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

3.1.2 Global aspects

The networks' maps clearly show that the overall observational capacity resulting from the combination of CARGO-ACT related networks provides a near-global capability for monitoring atmospheric aerosols, clouds, and trace gases. However, significant geographical gaps remain, and these gaps are largely common across the different observational domains. It is worth noting that other stations and networks are also present globally but are not shown in the site distribution maps in Section 2. However, even when these additional sites are taken into account, the overall conclusion regarding observational gaps remains the same.

The combined in situ network benefits from the integration of EU and US infrastructures, providing a relatively broad geographical distribution over those regions and beyond. Nevertheless, major gaps persist across the Southern Hemisphere, especially in Africa, South America, and large parts of Oceania. Remote continental interiors are generally poorly represented, while vast oceanic regions remain almost exclusively dependent on ship-based campaigns and temporary observations.

The PM2.5 level and population density reported in the following figure 3 and 4 highlights that Asia, Western and Central Africa, central America and part of the Western South America record the highest PM2.5 average values impacting areas with the highest density pollution. Limited integration with observational bodies there and the reduced observational capabilities available in those areas limit the effectiveness of current long-term observations for assessing global population exposure to pollution, and regional atmospheric composition changes.

Taken together, the ACTRIS, NFAN, MPLNET and ARM site distributions provide broad geographical coverage for in situ aerosol observations and aerosol profiling, although the coverage remains strongly concentrated in Europe and North America, while substantial observational capacity is also present in East Asia, Australia, Southern Africa, and parts of South America.

Despite this extensive coverage, important gaps remain over large portions of Central Africa, the Amazon Basin, Central Asia, Siberia, the Middle East, and most oceanic regions. The Southern Hemisphere remains generally less monitored than the Northern Hemisphere, particularly over continental interiors. High-latitude regions are also underrepresented relative to their importance for climate feedback studies. As a consequence, major aerosol source regions such as tropical biomass-burning areas (Figure 5), regions with the wider presence of active volcanoes (Figure 6) and rapidly developing regions affected by desert dust and anthropogenic pollution (Figure 3) are still insufficiently sampled by long-term, quality-assured remote sensing observations.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

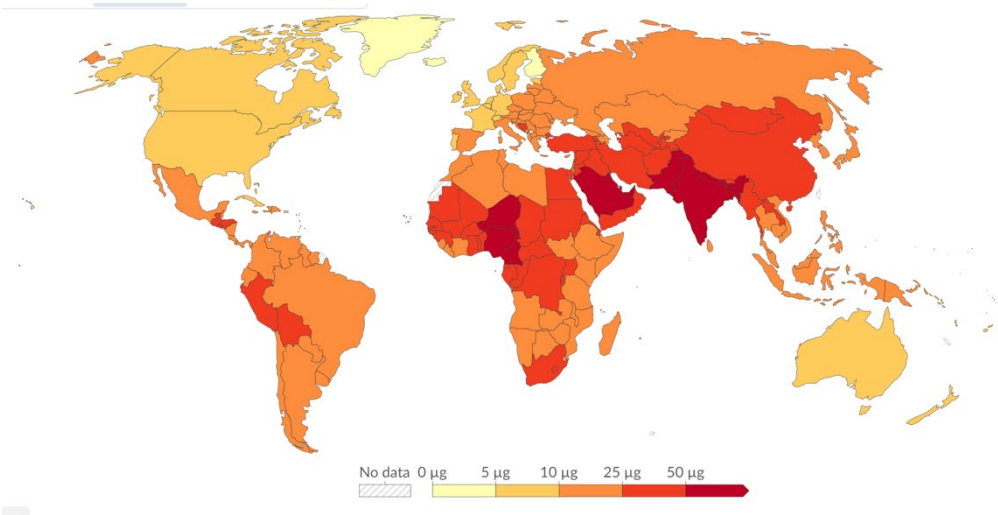


Figure 3. Global Population-weighted exposure to ambient PM2.5 pollution annual average for 2023 (https://ourworldindata.org/grapher/average-exposure-pm25-pollution).

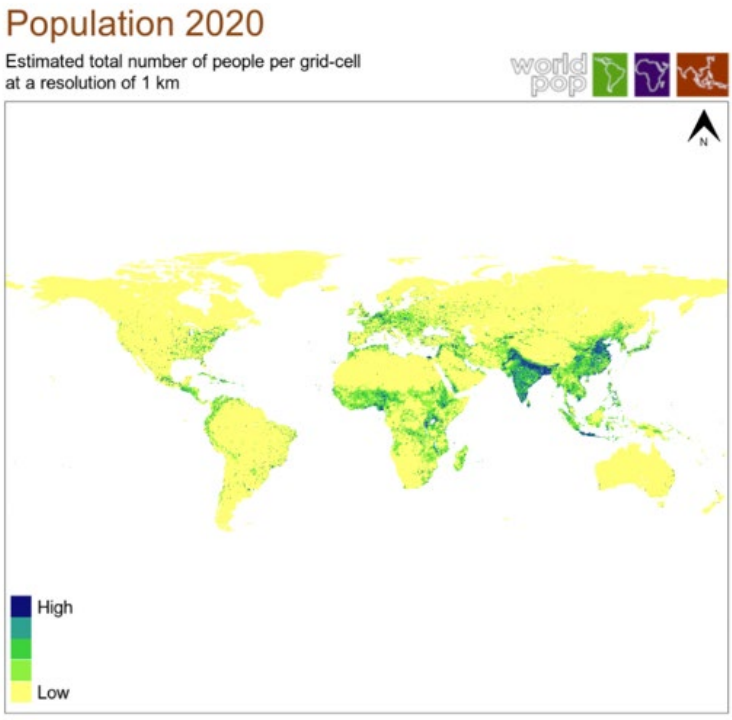


Figure 4. Global density population for 2020 (Source: WorldPop, 2018; https://hub.worldpop.org/geodata/summary?id=24777).

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

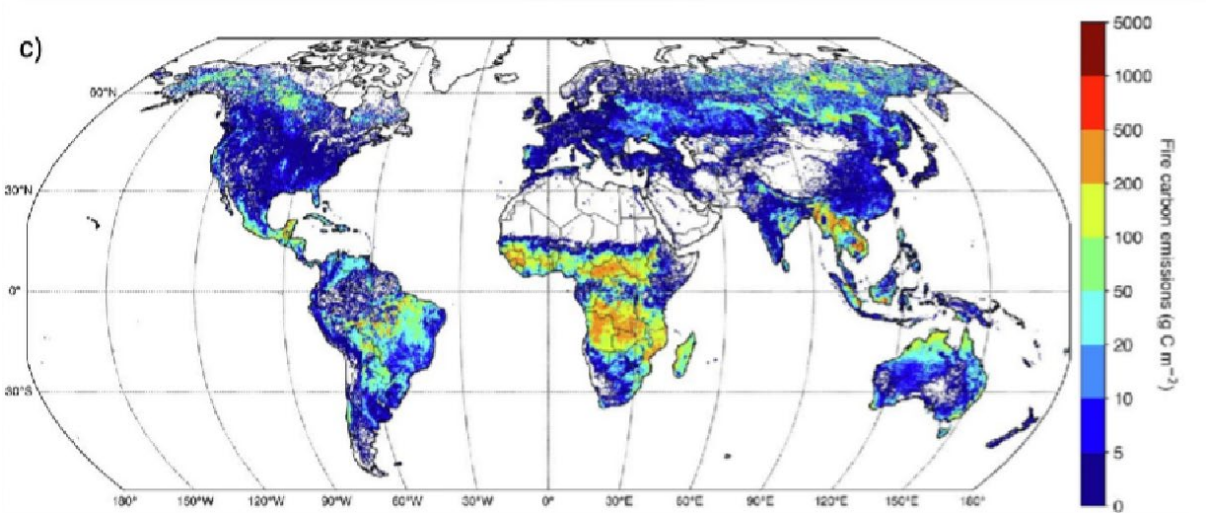


Figure 5. Mean annual fire carbon emissions for forest fires from GFED5 on its native 0.25° grid, averaged over 2002–2022 (Source: van der Werf, et al. 2025).

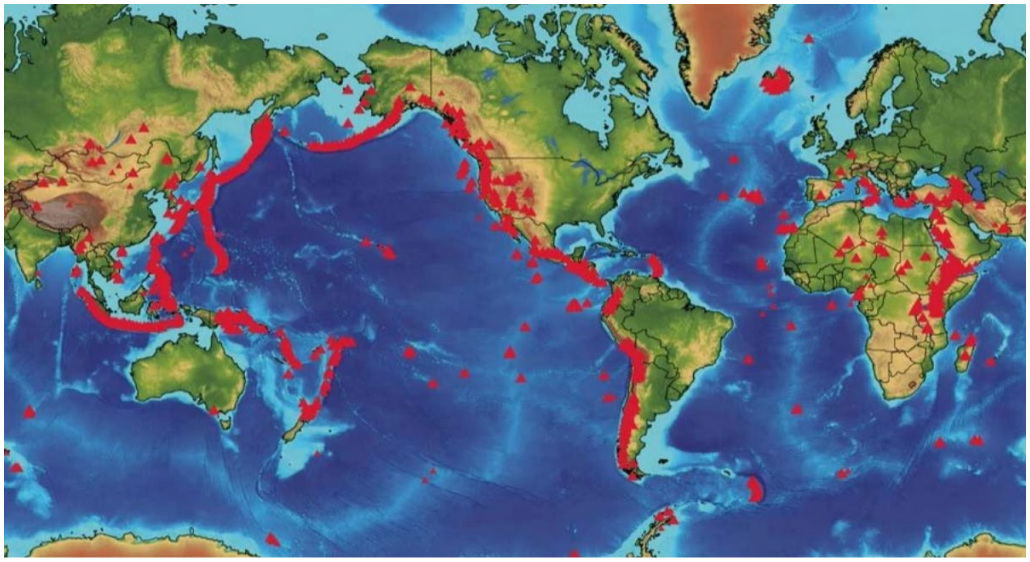


Figure 6. Map of the world showing locations of volcanoes. Image available on the Smithsonian Institution's Global Volcanism Program (http://www.volcano.si.edu/world/find_regions.cfm).

The cloud remote sensing network provides valuable global coverage but remains concentrated in Europe, with a few additional sites in North America and at selected supersites. Cloud measurements generally require more complex and expensive instrumentation than aerosol observations, resulting in a lower spatial density of stations.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

Major gaps are evident across Africa, South America, Central Asia, the polar regions, and most tropical oceanic areas. These are precisely the regions where cloud processes exert a strong influence on the Earth's radiation budget and where uncertainties in weather and climate models remain largest. The scarcity of long-term cloud profiling observations in these regions limits our ability to constrain cloud-climate feedback and evaluate numerical model performance on a global scale.

The current distribution of CARGO-ACT related networks for trace gas remote sensing stations reveals a heterogeneous global observational coverage. The highest density of sites is found in Europe and in US, with additional clusters in East Asia and at a number of strategically located stations in polar and tropical regions. Although the network provides representation across a broad range of climatic and atmospheric regimes, significant geographical gaps remain. Large areas of Africa, South America, the Middle East, Central Asia, Oceania, and remote oceanic regions are characterized by sparse or absent observations. Some of these regions are characterized by strong anthropogenic emissions growth, biomass-burning activity, and rapid urbanization. Consequently, the global capability to monitor long-term trends and validate satellite trace gas observations remains uneven.

Overall, the most evident global pattern is the strong concentration of observations in Europe and other highly developed regions. Coverage progressively decreases toward the tropics, the Southern Hemisphere, polar regions, and remote continental interiors. Although the existing network configuration provides excellent capability for process understanding, instrument harmonization, and satellite validation, significant observational gaps remain in regions that are particularly important for climate change, biomass burning, desert dust emissions, tropical convection, and rapidly growing anthropogenic emissions.

Future efforts would therefore provide the greatest scientific benefit if directed toward:

- Central and Western Africa,
- the Amazon Basin and tropical South America,
- Central and South Asia,
- high-latitude Arctic regions,
- remote Pacific, Atlantic, and Southern Ocean sectors, and
- emerging megacity regions in the Global South.

Linkages with existing networks in those regions and when needed improving observational capability there would significantly improve the representativeness of the global observing system and enhance the capability to quantify atmospheric processes and environmental impacts at planetary scale.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

3.2 Data provision gaps

In a changing climate, **NRT data provision** (near real-time data defined as within 3 days after acquisition) is a request for hazardous cases management from international, national, and regional authorities. Forest fires emission can affect level of pollution not only close by location, contributing to the increase of PM levels even at thousand km of distance (ACTRIS, 2025): local authorities could need high-quality observations in NRT as tool for the remediation plans. High-quality observations are essential when decisions are taken because these allows for measurements which are more quantitative and affected by lower uncertainities respect to the low-cost sensors. These latter are certainly relevant for such kind of applications, but their measurements have typically high error (statistical + systematic) and need to be somehow checked and calibrated. Only the combination of both of them is needed for a more complete representation: some high-quality points as reference coupled with a dense low-cost sensor network for improving the geographical (and temporal) coverage.

The same applied to desert dust occurrences that in US and EU can lead to health issues (Li et al., 2025). An example of international request for NRT observational data was the big and highly impacting eruption of the Eyjafjallajökull volcano in Iceland in 2010, when the aviation traffic was inhibited in almost the whole Northern Hemisphere for more than 2 weeks.

In the context of extreme events driven by climate change the request for NRT data is becoming more and more pressing. Currently no one of the CARGO-ACT participating network has NRT provision as its own mandate, but this is an achieved result for some networks and some variables (see Table1). Nevertheless, this can still be further improved for some of them. A facilitating option for filling the gap about NRT delivery is to implement central processing facilities that can deliver data more rapidly than some individual research groups can do.

Table 1. NRT provision for different CARGO-ACT networks.

	In situ	Aerosol profiling	Cloud profiling	Trace gases profiling
ACTRIS	partially	yes	yes	no
ARM		yes	yes	
MPLNET		yes		
NDACC				yes
NFAN	yes			

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

4 Potential strategies for filling the gaps

Possible approaches for reducing the current observational gaps should combine technological innovation, improved integration between existing infrastructures, and the deployment of more flexible observing systems.

4.1 Deployment of mobile platforms

A first strategy involves the deployment of mobile observing platforms capable of providing temporary or campaign-based measurements in regions where permanent infrastructures are currently absent or sparsely distributed. Mobile lidar systems, portable in situ laboratories, mobile cloud radars, and transportable atmospheric observatories can significantly increase observational coverage in strategic locations while avoiding the costs associated with the establishment of permanent stations. This is an approach ARM has taken with their ARM Mobile Facilities (AMFs) which have been deployed on all continents for periods of 6 months to 2 years (https://arm.gov/capabilities/observatories/amf), starting with the first deployment in 2005. Such platforms could be particularly valuable in tropical regions, emerging economies, remote continental areas, and regions frequently affected by extreme events such as wildfires, volcanic eruptions, dust storms, and pollution episodes. Similarly, ACTRIS runs mobile platform for different atmospheric variable characterization in temporary locations. These can used even in request through specific application/review process. The temporary observations could be a testbed for evaluating alternative methods like the ones reported hereafter.

The use of ceilometers (and in particular depolarizing ceilometers), which are substantially less expensive, easier to operate than advanced research lidars and widely distributed, offers an additional opportunity to expand aerosol and cloud profiling capabilities, albeit with more limited capabilities, e.g., restricted to lower troposphere.

When operated following harmonized protocols and quality assurance procedures, these instruments can provide valuable information on aerosol layer structure, cloud occurrence, and atmospheric boundary layer dynamics.

An additional opportunity lies in strengthening collaboration with national meteorological and weather-service networks worldwide that operate ground-based remote-sensing instruments for aerosol, cloud, and meteorological profiling, including automatic lidars and ceilometers for aerosols and clouds, microwave radiometers for temperature and humidity profiling, and Doppler lidars for wind profiling. Relevant examples include E-PROFILE in Europe and corresponding operational networks in the United States, with similar potential in other regions of the world.

Similarly for trace gases profiling, the development of more compact and cheaper instruments (e.g. Chouza, F., et al. (2025)) could be key for a better coverage in less developed countries.

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

At the same time, observational capacity can be enhanced through the application of advanced retrieval algorithms capable of extracting additional information from existing measurements. Multi-instrument inversion approaches such as GRASP (Generalized Retrieval of Atmosphere and Surface Properties) (Herrera et al., 2022) enable the synergistic exploitation of remote sensing observations, significantly increasing the amount and quality of retrieved aerosol microphysical and optical properties. Such methodologies allow existing stations to provide information that would otherwise require additional instrumentation, thereby partially compensating for limitations in geographical coverage while increasing the scientific value of current observations.

Technological innovation is key, also for enabling observations in environmentally harsh environments such as the polar regions, mountainous regions and the tropics. Geopolitical issues also play an important role and require science diplomacy.

4.2 Integration of ground-based and satellite observations

Strengthening the integration between ground-based observations and satellite observing systems could also partially fill the observational gap. Earth observation missions, including recent atmospheric satellites such as EarthCARE, offers unprecedented opportunities to complement spatially sparse ground-based networks with continuous regional and global coverage. Firstly, ground-based observations are fundamental for the validation of model fields resulting from satellite data assimilation (e.g., in Copernicus wildfire watch (https://atmosphere.copernicus.eu/fire-emissions-watch-global-wildfire-emission-data-your-fingertips).

Additionally, in this context, data-driven AI techniques can assimilate information from multiple observational sources, combine satellite and ground-based measurements, and generate spatially continuous fields of atmospheric variables. Such approaches can support the reconstruction of aerosol distributions, cloud properties, and trace gas concentrations in regions where direct observations are limited. AI-based methods could also support the optimization of network design identifying locations where additional measurements would provide the highest scientific benefit. While these techniques cannot replace direct observations, they can substantially enhance the value of existing datasets and contribute to reducing the impact of current geographical coverage limitations.

5 Global perspective beyond the EU-US framework

While the considered networks focus primarily on Europe and the United States, they also provide observations outside such regional domains. In Section 3, we analysed the observational gaps in the global perspective, by the way the existing observational capabilities outside such networks should be considered. In the general GAW framework, CARGO-ACT2 could be the proper tool and funding

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

framework by which the connection with the other networks could be strengthened and residual observational gaps addressed through devoted plans.

Indeed, many of the scientific challenges associated with air quality, climate change, atmospheric composition, and extreme events are inherently global and require observational capabilities extending far beyond the transatlantic domain. Future developments should therefore aim not only at strengthening the existing EU–US collaboration, but also at fostering the integration of observing systems operating in other continents and underrepresented regions.

Linkages with INDAAF, ASCENT, but also to additional networks joining CARGO-ACT2 during the project, with the collaboration of WMO, could significantly contribute to further harmonization of measurement protocols, quality assurance procedures, data formats, and retrieval methodologies across different regions. Linkages other regional initiatives would allow the development of a more coherent and interoperable global observing system. Such efforts would facilitate the generation of globally consistent datasets supporting satellite validation activities, climate monitoring, model evaluation, and large-scale atmospheric process studies.

Despite the significant observational capabilities currently available through existing international networks, important geographical gaps remain outside the EU and US domains. The current situation reflects the combination of groups' choices and national/regional capacity to support them. This led to a somehow uneven observational coverage. In the future plans, this limitation should be overcome assuring that the stations and measurements developments are driven more the effective needs for scientific progresses and services rather than research interest and capacity.

These gaps are particularly evident in Africa, the polar regions, and Australia–Oceania, where observational infrastructures are generally sparse, unevenly distributed, or characterized by limited long-term sustainability. As many of these regions are undergoing rapid environmental and climatic changes, improving observational coverage should be regarded as a strategic priority for the international atmospheric research community. The Arctic and Antarctic regions are experiencing some of the most rapid climate changes on Earth and play a key role in global climate feedback mechanisms. The establishment of stronger links between polar observing programmes and existing atmospheric research infrastructures would significantly improve long-term monitoring and data interoperability.

From a strategic perspective, future international cooperation efforts should focus not only on increasing the number of observing sites, but also on improving interoperability, data sharing, harmonization of observational procedures, and coordinated access to infrastructures. A globally connected observing system capable of integrating observations from Europe, North America, Africa, the polar regions, Oceania, and other emerging observational domains would provide a more robust foundation for atmospheric research, operational services, climate assessments, and satellite validation activities. In this

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093

context, CARGO-ACT2 could play an important role as a catalyst for strengthening international partnerships and supporting the development of a truly global atmospheric observing framework.

6 References

ACTRIS newsletter, ACTRIS Tracks Canadian Wildfire Smoke Reaching Europe, June 2025, https://www.actris.eu/news-events/news/actris-tracks-canadian-wildfire-smoke-reaching-europe

Chouza, F., Leblanc, T., Wang, P., Brown, S. S., Zuraski, K., Chace, W., Womack, C. C., Peischl, J., Hair, J., Shingler, T., and Sullivan, J.: The Small Mobile Ozone Lidar (SMOL): instrument description and first results, Atmos. Meas. Tech., 18, 405–419, https://doi.org/10.5194/amt-18-405-2025, 2025.

Herrera, M. E., Dubovik, O., Torres, B., Lapyonok, T., Fuertes, D., Lopatin, A., Litvinov, P., Chen, C., Benavent-Oltra, J. A., Bali, J. L., and Ristori, P. R.: Estimates of remote sensing retrieval errors by the GRASP algorithm: application to ground-based observations, concept and validation, Atmos. Meas. Tech., 15, 6075–6126, https://doi.org/10.5194/amt-15-6075-2022, 2022.

Li T, Cohen A, Krzyzanowski M et al. Sand and dust storms: a growing global health threat calls for international health studies to support policy action The Lancet Planetary Health, 9, e34-e40, 2025.

Mona, L., E, O'Connor, M. De Maziere, E. Juurola, D. Nicolae, J. Welton, C. Lund Myhre, M. Fiebig, O. Mayol-Bracero, M- Haeffelin, CARGO-ACT Deliverable 4.1: International memorandums of understanding signed, 2024.

van der Werf, G.R., Randerson, J.T., van Wees, D. et al. Landscape fire emissions from the 5th version of the Global Fire Emissions Database (GFED5). Sci Data 12, 1870 (2025). https://doi.org/10.1038/s41597-025-06127-w

Worldpop, www.worldpop.org - School of Geography and Environmental Science, University of Southampton; Department of Geography and Geosciences, University of Louisville; Departement de Geographie, Universite de Namur) and Center for International Earth Science Information Network (CIESIN), Columbia University (2018). Global High Resolution Population Denominators Project - Funded by The Bill and Melinda Gates Foundation (OPP1134076). https://dx.doi.org/10.5258/SOTON/WP00647

CARGO-ACT (www.cargo-act.eu) is supported by the European Commission under the Horizon Europe (HORIZON) – Strengthening the international dimension of ESFRI and/or ERIC research infrastructures, HORIZON-INFRA-2023-DEV-01-07, Grant Agreement #: 101132093