Annual Report 2022

IAGOS

IN-SERVICE AIRCRAFT FOR A GLOBAL OBSERVING SYSTEM

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Report approved: **11.03.2022**

Letter from the President of IAGOS-AISBL

Dear Colleagues and Friends of IAGOS,

In 2022, we welcomed Eurowings Discover to IAGOS. This new aircraft was equipped in April and is based in Frankfurt, increasing the sampling at Frankfurt airport and the statistical robustness of this important dataset, along with profiles for validation of air quality models. The aircraft covers many new routes in Africa and the Caribbean which enhances the geographical spread of the IAGOS data.

The implementation of IAGOS Germany was successfully terminated in 2022 and in December we welcomed State Secretary Judith Pirscher from the German Federal Ministry of Education and Research (BMBF) visited Forschungszentrum Jülich to pay tribute to the successful work of IAGOS Germany.

There is much to look forward to in 2023 with a new airline, Air Canada, in March and the return of Iberia in Autumn 2023. The upcoming installations of the greenhouse gas package and the NOX packages on the two China Airlines aircraft will further expand the range of Essential Climate Variables for the troposphere measured by IAGOS.

Yours Sincerely

Contents

Mission

The mission of IAGOS is to provide high quality data throughout the troposphere and lower stratosphere, and scientific expertise to understand the evolution of atmospheric composition, air quality, and climate.

Vision

IAGOS, using commercial aircraft, will be a crucial pillar of the global observing system, supporting societal needs for a greener and more sustainable future.

Version	Published	EB Approval	GA Approval
final	24.05.2023	15.05.2023	15.05.2023

Executive Summary

Since IAGOS was formed as an AISBL in 2014, it has been pursuing the objective of equipping 15-20 aircraft with the aim of feeding the data centre for the scientific community and operational services. This executive summary presents an overview of data, products and services provided by IAGOS which are important European contributions to the integrated global observation system monitoring the state of the Earth system and climate. It sets out how the IAGOS data has been used in regard to the UN sustainable development goals.

IAGOS in the Global Observing System

IAGOS has a central and unique role in the global observing system, providing important measurements in the vertical which surface stations do not provide, and important information in the climate-sensitive upper troposphere and lower stratosphere with a high resolution which satellites cannot acquire. Through ENVRI-FAIR we endeavour to ensure that the data are freely and easily accessible and maintain FAIR data standards. Together with ICOS and ACTRIS, the 2 other RIs from the atmospheric domain, we are working on further harmonisation of data products and services for the benefits of users. Mid-way through the 4-year project ATMO-ACCESS, a series of recommendations for establishing a comprehensive and sustainable framework for access to distributed atmospheric Research Infrastructures has been developed. IAGOS is a contributing network to the WMO Global Atmosphere Watch program and our data are used in the daily monitoring of global air quality models via the Copernicus Atmosphere Monitoring Service which has been operational for more than six years.

IAGOS Operations

Technology and measurements

The move of the IAGOS-CARIBIC cargo container to an Airbus A350-900 aircraft of Lufthansa Group continues to advance. The revised supplemental type certificate (STC) for the P2d greenhouse gas package was obtained from EASA and the P2b package for nitrogen oxides was also certified. This diversifies the range of measurements that can be obtained from IAGOS-CORE and allows these instruments to be installed on all Airbus A330/340 aircraft operated by European airlines. China Airlines will be the first non-European airline to have the full range of options available with planned installation of the P2b and P2d in 2023.

Sustainability and stability

Key to IAGOS is the sustainability of the RI in the long-term and the stability of the data provision to ensure a long and continuous data-set for addressing climate issues. IAGOS will soon celebrate 30 years of measurements, becoming officially a data-set for climate research purposes as considered by the World Meteorological Organisation. Many of the articles cited below refer to the analysis of trends in atmospheric composition.

Development and Expansion

In 2022, a new aircraft was equipped. The aircraft is operated by Eurowings Discover. It regularly revisits Windhoek providing transects across the African continent and continuing the time-series begun by Air Namibia (2005-2013). Many new destinations in Africa, the Indian Ocean and the Caribbean are also visited. In 2022, IAGOS began the preparation work for several new installations which will expand the geographical coverage of the network. A new partnership with Air Canada will enhance the measurements in the climate sensitive regions of the far northern latitudes which are warming more than twice as fast as elsewhere and where the harsh environment makes obtaining in situ measurements particularly challenging. Air Canada will reinforce the measurements in the North Atlantic flight corridor which has been the backbone of IAGOS over the last 25 years and which is key to long-term climate monitoring. Agreement was also reached with Iberia for a new aircraft in 2023.

FAIR and Open Data: IAGOS, under the lead of Forschungszentrum Jülich, is coordinating the European ESFRI cluster project ENVRI-FAIR which is aiming towards easy and seamless access to research data and services from all sectors of the Earth system, provided by the community of European Environmental Research Infrastructures. Well advanced flagship Research Infrastructures like IAGOS with a high level of maturity, lead the development and implementation of common policies, open standards, interoperability solutions, operational services, and stewardship of data based on the FAIR principles. In this framework, IAGOS is continuously developing and improving its data management systems towards full compliance with the FAIR principles, with the long-term goal of exposing IAGOS data for interoperable use and interdisciplinary research on the ENVRI-Hub. The ENVRI-Hub will be the interface to the ENVRI ecosystem on the emerging service catalogue of the European Open Science Cloud. Major achievements reached in 2022 include the development of scientific show cases of the Atmospheric subdomain for future integration into the ENVRI-Hub, the implementation of a fully automated data processing workflow with embedded data quality assessment and control tools, the improvement of machine accessibility of IAGOS data and services, and the continuous improvement of the IAGOS online presence.

Executive Summary

Sustainable Development Goals

By nature IAGOS is committed to being relevant to several of the UN sustainable development goals.

SDG 13 "Climate Action": IAGOS has provided continuous measurements of greenhouse gases and short-lived climate forcers on the global scale for almost thirty years. It is the continuity of measurements that enables us to assess the impact of mitigation policies and emissions protocols. IAGOS is one of the most important datasets of in-situ observations in the upper troposphere-lower stratosphere with dense and high resolution measurements. Over several decades, IAGOS has acquired the essential characteristic of adding statistical robustness to climatologies and trend analyses. Therefore, IAGOS is important as a validation reference for climate and air-quality models and in the validation of satellite observations.

Work began on a new project ICOS-Cities, funded by the European Commission as part of the European Green Deal. ICOS-Cities is dedicated to the monitoring of greenhouse gas emissions over large cities where profiles from the P2d greenhouse gas package will be incorporated. This cooperation is largely with the ICOS research infrastructure.

IAGOS data are used to understand the **budget and trends of tropospheric ozone**. Chang et al. (2022) found that the negative anomalies of free tropospheric ozone during the COVID period in 2020 are the most profound since the benchmark year of 1994. Kumar et al. (2022) compared simulations of carbon monoxide over Africa with IAGOS data to look at source attribution and regional transport highlighting the need for regional coordination and cooperation for air quality management in Africa. Using CO as a tracer for atmospheric transport, Liu et al. (2022) examined teleconnections of El Niño and Southern Oscillation with the North Atlantic to better understand the co-transport of pollutants that are more difficult to measure, such as black carbon. Li et al. (2022) looked at trends of hydrocarbons, particularly ethane from IAGOS-CARIBIC to evaluate and improve atmospheric models and emission inventories, and understand long-term changes in troposphere-stratosphere exchange and in sources and sinks of ethane, methane and propane. Wang et al. (2022) observed tropospheric ozone trends, their attributions, and radiative impact. They estimated an increase in the radiative forcing from tropospheric ozone in 2013-2017 compared with 1995–1999.

IAGOS data are an essential independent dataset for the validation of **Earth System Models** routinely through the daily validation of the daily forecasts from the Copernicus Atmosphere Monitoring Service (CAMS) available online.

SDG 3, "Good Health and Well Being": IAGOS provides essential information on the composition of the atmosphere throughout the troposphere over different regions. IAGOS data are transmitted in near real-time to real-real time to the operational services of Copernicus and contribute to the improvement of air-quality models allowing monitoring and forecast (www.iagos-data.fr/cams), and assessment of mitigation scenarios. Work started on the project RI-URBANS, a project funded by the European Commission for the European Green Deal, and dedicated to developing new tools and services to aid improvement of urban air quality models. This cooperation is largely with the ACTRIS research instructure.

Two articles (Koening et al., 2022 and Custódio et al., 2022), exploited the measurements of atmospheric mercury made by the IAGOS-CARIBIC container. Mercury is a volatile and toxic heavy metal that poses risks to humans and ecosystems and accumulates in the aquatic food chain. It is therefore covered by the Stockholm convention. The two articles address uncertainties in the sources and transport of atmospheric mercury and help the United Nations Environment program with their aim of improving global understanding of international mercury emission sources and evaluating the global emissions inventories.

SDG 11 "Sustainable Cities and Communities": With the involvement of IAGOS in the two European Green Deal projects, ICOS-Cities (PAUL) and RI_URBANS, IAGOS is making a new contribution to sustainable cities and communities. 'ICOS Cities (PAUL – Pilot Applications in Urban Landscapes)' which is a Horizon 2020 project that aims to develop a systematic greenhouse gas measurement system for urban areas. Urban areas contribute to a large share of global and European fossil fuel emissions and cities are therefore at the heart of emission reduction efforts. RI-URBANS aims to identify and address the risks posed to human health by urban air quality and in particular by airborne particulate matter. In both projects, IAGOS works closely with the ICOS and ACTRIS research infrastructures.

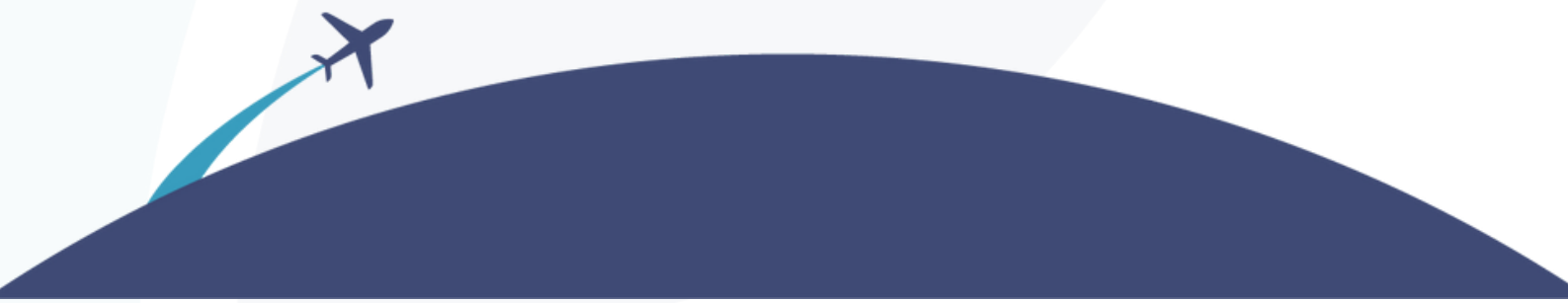
SDG 9 "Industry, Innovation and Infrastructure": As an infrastructure we are implementing global standards for measuring air-quality indicators that meet the standards of the World Meteorological Organisation. We are ensuring that our data meets the FAIR criteria and are coordinating the ENVRI-FAIR project.

Aviation Industry: IAGOS data is playing an increasing role in understanding the **impacts of aviation on climate** and understanding the **impacts of the environment on aviation**. Several articles published this year address these themes.

Using 8 years of data from the BCP on IAGOS, Raga et al. (2022) found that the particles emitted by biomass burning and pollution from mega cities act as nuclei on which ice-crystals can form, and increase the likelihood of extreme ice crystal events. This study has implications for contrail formation in busy air corridors over Asia. Prashanth et al 2022 pointed to the importance of knowing the background amounts of ozone, as provided by IAGOS, in the upper troposphere and lower stratosphere for a better assessment of the radiative forcing from aviation emissions. Wang et al. (2022) highlighted a previously under-appreciated increase in tropospheric ozone produced via reactions with NOx emitted by aircraft. This aircraft-induced increase accounts for 66% of the ozone trends. This large contribution is because aircraft NOx emissions are mainly released in the mid- and upper troposphere, where water vapour content is lower, the NOx level is low, and lifetime of NOx is longer, leading to higher ozone production efficiency. Voigt et al., (2022) found that the 80% decline in air traffic led to substantial reductions in nitrogen oxides at cruise altitudes, in contrail cover, and in resulting radiative forcing.

The article by Gierens et al. (2022) used water vapour from IAGOS to improve understanding of the formation of ice-super saturated regions, necessary for a better understanding of contrail formation and non-CO2 effects of aviation. Teoh et al. (2022) benefited from the long time series of water vapour measurements from IAGOS, using 6 years of data over the North Atlantic to validate and scale the modelled relative humidity fields for a better estimation of ice supersaturated regions.

Turbulence is an important aviation weather hazard which may increase in severity or frequency with a changing climate. Kaluza et al. (2022) used IAGOS data to define the position of the tropopause, along with pilot reports of turbulence to find that turbulence maximises just below the tropopause. Such a study will help improve models to identify and forecast atmospheric turbulence.



Key Performance Indicators (KPIs)

The KPIs are based on the 10 chosen KPIs from the list of 21 proposed by ESFRI. We implemented these KPIs for the first time in 2020 and the same KPIs are reported here for 2022 along with a few additional KPIs pertaining to the operations of IAGOS.

Expansion of the Fleet

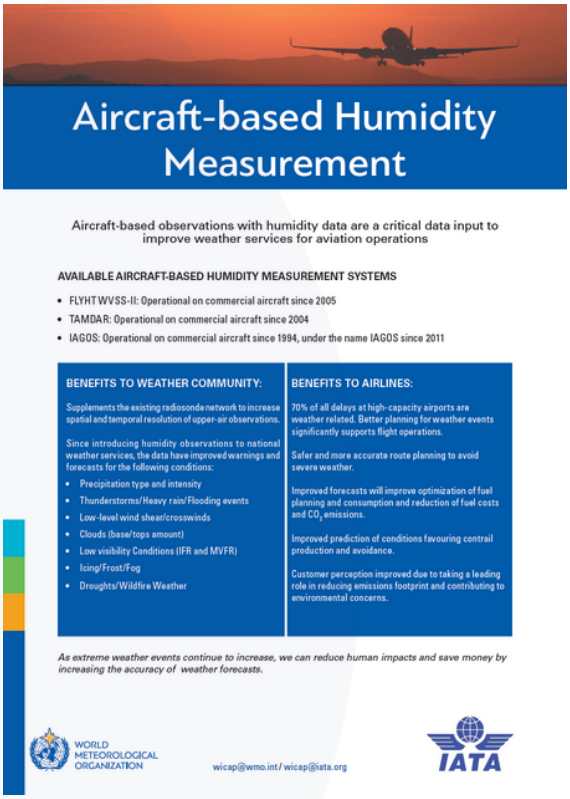
In 2022, a new aircraft was equipped and is operated by Eurowings Discover. It regularly visits Windhoek, providing transects across the African continent and continuing the time-series started by Air Namibia. Many new destinations in Africa, the Indian Ocean and the Caribbean are also served on a regular basis.

The IAGOS team has worked with Air Canada for the installation in early 2023 following the signature of the contract in 2022. This partnership will support the long-term climate monitoring over the North Atlantic and enhance the historic Canadian ozonesonde network through collaborations with Environment Canada. IAGOS ideally complements the ozonesonde network through a higher frequency of measurements and provides measurements of ozone precursors and other greenhouse gases in addition. There will be daily profiles over Canadian cities for monitoring air quality and for the validation of North American air quality models for tracking wildfire plumes across the continent.

A new agreement has been reached with IBERIA (IAGOS partner from 2014-2016) installation planned for the end of 2023. The new aircraft will provide crucial climate data across the the south Atlantic as well as air quality data in Southwest Europe and South America.

Aircraft Based Observations

IAGOS humidity sensors, along with two other systems, are now highlighted in this publication by the WMO and IATA, for obtaining measurements of water vapour in the upper troposphere and lower stratosphere. The leaflet highlights the importance of humidity sensors and their importance to the weather community.



Aircraft-based Humidity Measurement

Aircraft-based observations with humidity data are a critical data input to improve weather services for aviation operations

AVAILABLE AIRCRAFT-BASED HUMIDITY MEASUREMENT SYSTEMS

- FLYHT WVSS-II: Operational on commercial aircraft since 2005
- TAMDAR: Operational on commercial aircraft since 2004
- IAGOS: Operational on commercial aircraft since 1994, under the name IAGOS since 2011

BENEFITS TO WEATHER COMMUNITY:

Supplements the existing radiosonde network to increase spatial and temporal resolution of upper-air observations.

Since introducing humidity observations to national weather services, the data have improved warnings and forecasts for the following conditions:

- Precipitation type and intensity
- Thunderstorms/Heavy rain/Flooding events
- Low-level wind shear/crosswinds
- Clouds (base/tops amount)
- Low visibility Conditions (IFR and MVFR)
- Icing/Frost/Fog
- Droughts/Wildfire Weather

BENEFITS TO AIRLINES:

70% of all delays at high-capacity airports are weather related. Better planning for weather events significantly supports flight operations.

Safer and more accurate route planning to avoid severe weather.

Improved forecasts will improve optimization of fuel planning and consumption and reduction of fuel costs and CO_2 emissions.

Improved prediction of conditions favouring contrail production and avoidance.

Customer perception improved due to taking a leading role in reducing emissions footprint and contributing to environmental concerns.

As extreme weather events continue to increase, we can reduce human impacts and save money by increasing the accuracy of weather forecasts.

WORLD METEOROLOGICAL ORGANIZATION

wicap@wmo.int / wicap@iata.org

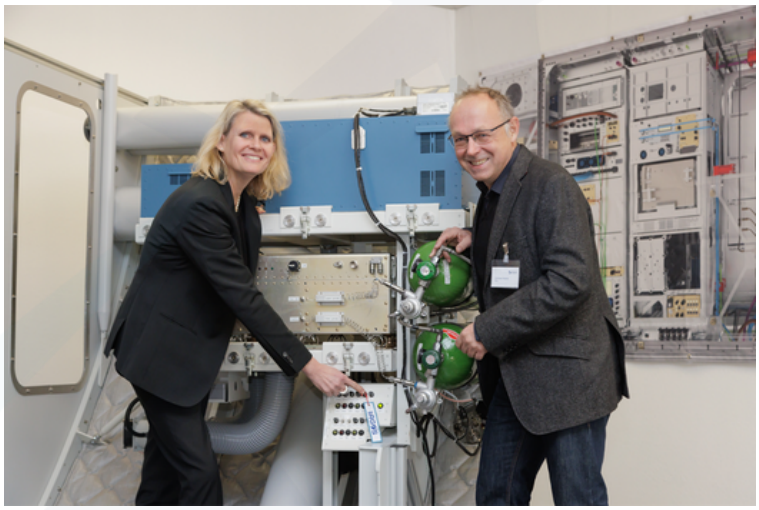
IATA

Implementation of IAGOS Germany Successfully Finished

After 10 years of support by the German Ministry for Education and Research, the implementation of Germany's contributions to IAGOS haven been successfully finished and handed over to the scientific community for operation. On 13 December 2022, State Secretary Judith Pirscher from the German Federal Ministry of Education and Research (BMBF) visited Forschungszentrum Jülich to pay tribute to the successful work of IAGOS Germany.

BMBF has provided IAGOS with around € 18.7 million in funding since 2012. State Secretary Judith Pirscher was visibly impressed with all that has been achieved so far: "If we want to stop climate change, we have to understand it better. IAGOS, as a first-class and unique research infrastructure, is making a considerable contribution to this effort. It unites science and civil aviation in a very unique manner. Commercial aircraft bring the data directly from the atmosphere down to the ground. No additional, climate-damaging flights are necessary for the measurements. In this way, we gain globally valuable data for climate research, which also help to improve weather forecasts. This knowledge provides the basis for political decisions on climate protection and in adapting to the effects of climate change."

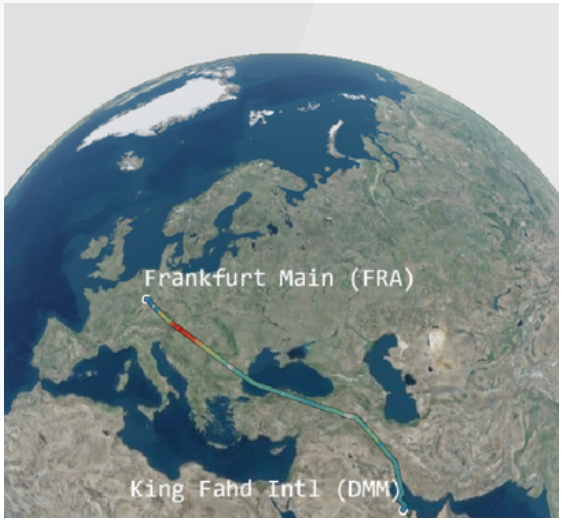
"IAGOS has developed into a research infrastructure of international standing and occupies a central place in the global system for observing the atmosphere. Thanks to our work with national and international research partners, we have succeeded in establishing an efficient infrastructure that is now transitioning to continuous operation, thus demonstrating the successful transfer of the idea to the infrastructure. The measurement data are currently used by around 300 organizations worldwide – and IAGOS hopes that our data will be used for even broader research in the future," says Andreas Petzold.



State Secretary Judith Pirscher from the German Federal Ministry of Education and Research and IAGOS-D coordinator Prof. Andreas Petzold from the Institute of Energy and Climate Research – Troposphere at Forschungszentrum Jülich Copyright: — Forschungszentrum Jülich/Ralf-Uwe Limbach
Full article at https://www.fz-juelich.de/en/news/archive/press-release/2022/iagos-successful-atmospheric-research

Launch of the New Data Centre

The new data portal was launched in April 2022. The data portal includes more added-value products and services along with interactive plotting tools developed thanks to funding from ENVRI-FAIR and ATMO-ACCESS.



3-D Visualisation of a flight from Frankfurt to Dammam coloured by ozone mixing ratios.

Scientific Highlights

Annual Meeting In Toulouse

The Annual Meeting took place over three days in September in Toulouse. The event was an opportunity to catch up with the latest scientific and technological developments across IAGOS. A session was dedicated to the benefits of IAGOS to the aviation sector and to develop and enhance the cooperation with Airbus.

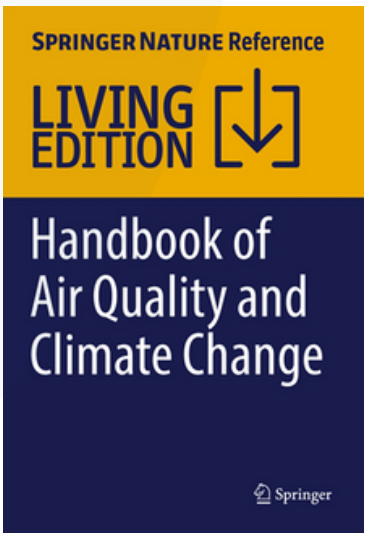
Annual Meeting in Toulouse, September 2022.

Atmospheric Mercury from IAGOS-CARIBIC

Two articles (Koenig et al., 2022 and Custódio et al., 2022) exploited the measurements of atmospheric mercury (Hg) made on board the IAGOS-CARIBIC container. Mercury is a volatile and toxic heavy metal that poses risks to humans and ecosystems and accumulates in the aquatic food chain. It is therefore covered by the Stockholm convention. The two articles address uncertainties in the sources and transport of atmospheric mercury and help the United Nations Environment program with their aim of improving global understanding of international mercury emission sources and evaluating the global emission inventories. Koenig et al. (2022) looked at the transport of atmospheric mercury to identify Hg sources and the seasonality of Hg emissions related in particular to biomass burning. Custódio et al. (2022) used observations of atmospheric mercury from IAGOS-CARIBIC to identify hotspots of mercury emissions to better understand the global emission inventory of mercury.

Handbook of Air Quality and Climate Change

IAGOS contributed a chapter "Monitoring Atmospheric Composition for Air Quality and Climate by Passenger Aircraft" (Thouret et al., 2022) to the Handbook of Air Quality and Climate Change published by Springer and edited by Hajime Akimoto and Hiroshi Tanimoto. The handbook looks at the role of pollutants as short lived climate forcers, and their impact on human health, ecosystems and climate change. The chapters cover the different systems in place for measuring and monitoring air quality including satellites, surface stations and IAGOS, with other chapters considering the effects of pollutants on ecosystems and climate.

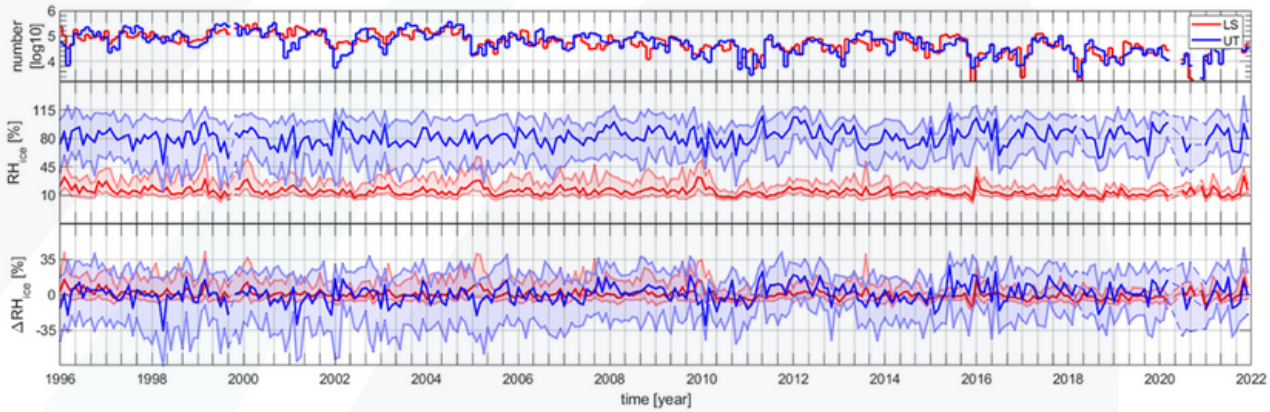


Cover of the Handbook

Water Vapour Time-Series

The IAGOS water vapour time-series from 2011 to 2021 was released as a L2 product. Due to the long time series and the high data density of the combined data set of IAGOS and MOZAIC, this data-set is ideally suited to investigate the long-term characterization of water vapour distribution in the Extratropical Upper Troposphere and Lower Stratosphere (Ex-UTLS) .

This data-set is currently used to compare the distribution of absolute humidity, temperature, relative humidity with respect to ice (RH_{ice}) and the occurrence of Ice Super-Saturated Regions (ISSRs) for different years and seasons and to investigate the associated long-term changes. The focus of this study lies on different altitude levels in the UTLS at northern mid-latitudes over the regions Eastern North America, North Atlantic and Europe. First results of this study were presented at international conferences (see conference presentations).



Time series of RH_{ice} over the North Atlantic from 1996 to 2021. First analyses show no significant trends for this period in the UT and LS.

EOSC Environmental Dashboard

Keeping a close watch on environmental boundary conditions and informing society stakeholders of their short- and long-term developments is not only important for the environment but also crucial to the economy. IAGOS is working with other infrastructures in the ENVRI project to develop a 'dashboard' with a set of easily understandable real-time environmental indicators which can be used to inform both the broader public and policymakers on the state of the environment. The dashboard will be mounted as a front-end of the ENVRI-Hub, a virtual common platform for ENVRI-FAIR data and services that will be integrated into the European Open Science Cloud platform.

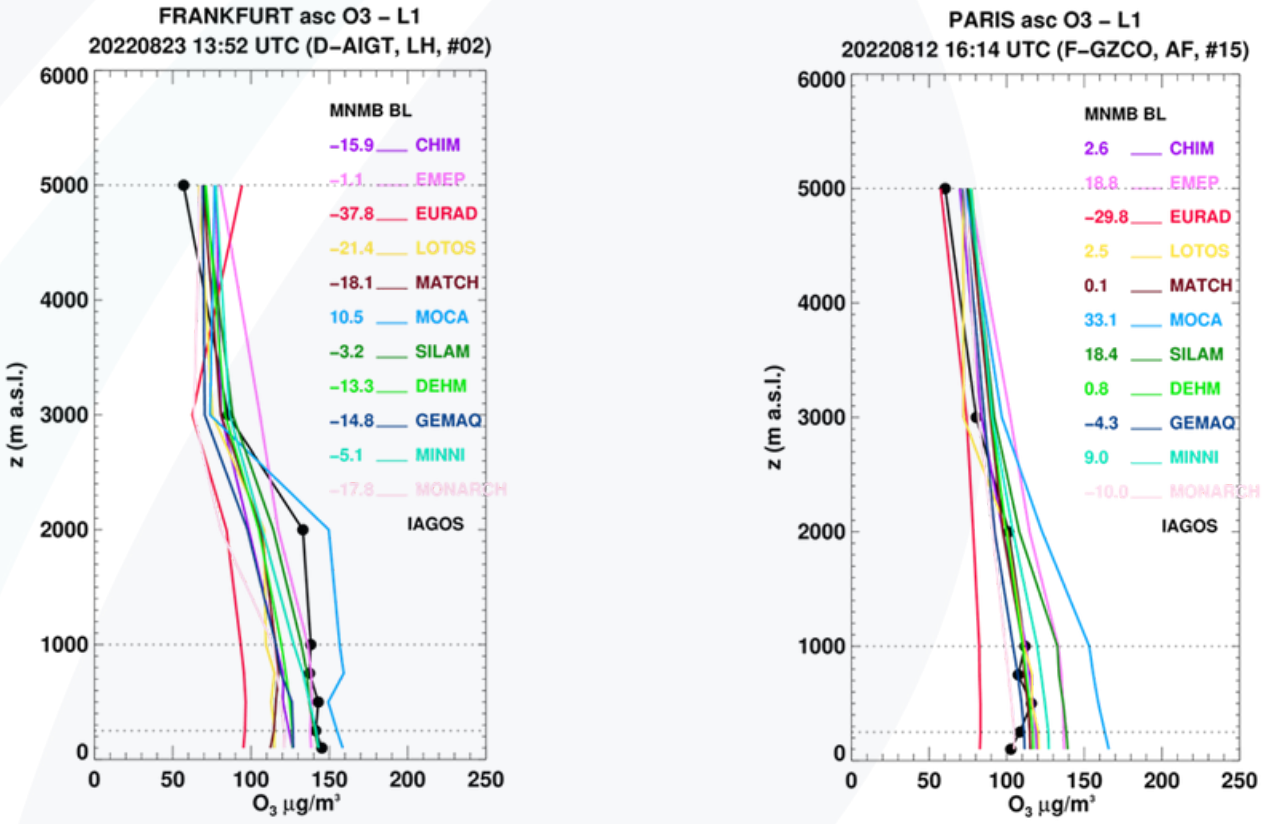
The figure above shows an example of the format of the environmental indicators provided by IAGOS.

Next Phase of CAMS Services

The next phase of the Copernicus Atmosphere Monitoring Service began in 2002. CNRS represents IAGOS in this consortium in the two branches CAMS2-82 for the global validation led by KNMI and CAMS2-83 for validation of the regional models led by Met-Norway.

Summer 2022 saw numerous heatwaves across Europe accompanied by record wildfires in South Western France. As part of the Copernicus Atmosphere Monitoring Service (CAMS), IAGOS produces daily validation of the global and regional models.

There are now 11 regional models in this validation corresponding to the 11 coloured lines in the plot below. During August, the CAMS forecasts predicted peaks in the daily maximum surface ozone levels, well above the threshold of 100 µg/m³ considered safe by the World Health Organization and often above the European threshold of 120 µg/m³ in several European cities as the IAGOS profiles at Frankfurt and Paris confirmed.



The figure above shows examples of the IAGOS ozone (black) observed at Frankfurt (left) and Paris (Right) during heatwaves in 2022, along with 11 regional air-quality models from groups across Europe. The plots are made routinely for the CAMS project CAMS2-83.

Organisation

IAGOS-AISBL

IAGOS is organised as an International not-for-profit Association (AISBL) with its seat in Brussels.
Members of IAGOS-AISBL are:

Forschungszentrum Jülich GmbH
Jülich, Germany (FZJ)

Centre National de la Recherche Scientifique
Paris, France (CNRS)

Max-Planck Gesellschaft zur Förderung der Wissenschaften e.V.
München, Germany (MPG)

Météo France
Toulouse, France (MF)

The University of Manchester
Manchester, United Kingdom (UMAN)

Deutsches Zentrum für Luft- und Raumfahrt e.V.
Köln, Germany (DLR)

Leibniz-Institut für Troposphärenforschung e.V.
Leipzig, Germany (TROPOS)

Karlsruher Institut für Technologie
Karlsruhe, Germany (KIT)

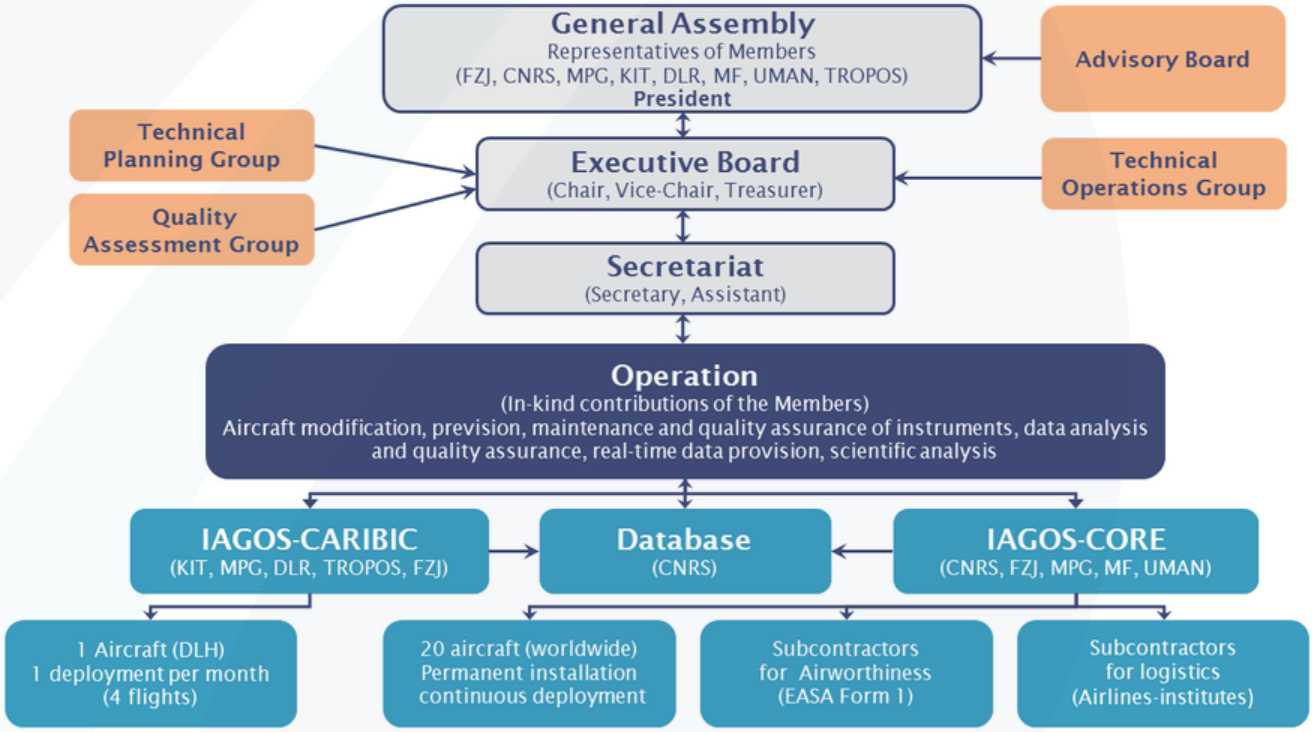
Activities of IAGOS-AISBL

The activities of IAGOS-AISBL are twofold (Statutes are available for download at http://www.iagos.org):

- Activities conducted by the organs of the Association
- Coordination of the technical and scientific activities carried out by the Members from their own resources.

The governance structure of the Association is shown below. The General Assembly (GA) is the highest decision making body. It is composed of the representatives of the Members and is chaired by the President, Andreas Wahner, representative of FZJ. Jean-Marie Flaud, representative of CNRS, serves as Vice-President.

The daily management is conducted by the Executive Board (EB). It is composed of Martin Gallagher, Andreas Petzold (Treasurer), Valerie Thouret (Chair), Andreas Zahn (Vice-Chair) , Christoph Gerbig and Hannah Clark (Executive Secretary).



An Advisory Board (AB) regularly reviews the progress made and gives advice to the Members of IAGOS-ASBL for future development and strategic orientation of the IAGOS research infrastructure in the global landscape. The members of the AB are: Jonathan Preist, Airbus, Toulouse (Chair); Arlyn Andrews NOAA-ESRL, USA; Volker Grewe, DLR Germany, and Delft University of Technology, The Netherlands; Gelsomina Pappalardo, CNR, Italy; Vincent-Henri Peuch, ECMWF, Germany; Cyril Crevoisier, LMD, France.

The Technical Planning group and Technical Operations Group oversee the technical operation and development of the infrastructure. The TOG works closely with the aeronautical subcontractors and the associated airlines. In 2021, these were: Deutsche Lufthansa, Air France, China Airlines, Cathay Pacific, Hawaiian Airlines and Iberia (see pictures below for details of the aircraft involved). The Quality Assessment Group (QAG) is in charge of the quality assurance and quality control of the data transferred to the data centre and the Data Management Group (DMG) is concerned with the data transmission chains and the evolution of the data centre.

For more information and statutes see www.iagos.org.

Activities of the Association

Executive Board

Activities of the Association included four meetings of the Executive Board, two meetings of the General Assembly, one meeting of the Advisory Board, and 2 Meetings of the Technical Planning Group.

20 January 2022
(5 EB members, P, VP, ES)

- Status of Operations and Planning
- Next steps for instrument deployment
- Preparation of the March GA
- Activity plan 2021
- Annual Report
- Updates on new EU projects
- ToR for DMG and QAG

21 April 2022
5 EB members, VP, ES

- Information on ESFRI evaluation
- Agenda and planning for the meeting in Toulouse
- Updates from ATMO-TECH
- CAMS2-27 and SESAR projects
- EGU and ENVRI Booth

15 June 2022
(5 EB members, P, VP, ES)

- Information of recent activities and developments (TPG, TOG DMG and QAG reports)
- Agenda and planning for the meeting in Toulouse
- Updates on EOSC dashboard
- SEAR project update
- CAMS2-27 update

22 September 2022
(5 EB members, P, VP, ES, HB)

- Comments and actions following the workshop
- Preparation of the GA meeting in November in Brussels
- Preparation of the AB meeting
- Activity Plan 2023
- Report of ES
- IAGOS-CORE for the A350

1 December 2022
(5 EB members, VP, ES)

- Summary of the General Assembly and Advisory Board meeting
- Website modifications
- Update on P2 installations and aircraft

General Assembly

11 March 2022

- Report from TPG and TOG Chairs
- Current status of IAGOS-CARIBIC
- Updates on projects and funding
- ENVRI-FAIR and demonstration of the new data portal
- Discussion on the recommendations of the AB
- Scientific achievements
- Approval of the Activity Plan and Implementation plan for 2022
- Decision on threshold for voting rights
- Approval of the Budget for 2022
- Approval of the suggested procedure for IAGOS-CORE on A350
- Approval of the Annual Report for 2021
- Approval of the ToR for the DMG and QAG
- Report from ES

15 November 2022

- Report on Operations and Planning
- Report from IAGOS-CARIBIC
- Report from Advisory Board Chair
- Report from Executive Board Chair
- Approval of the Budget for 2022
- Approval of the Activity Plan for 2022, pending availability of Members' resources (to be confirmed in spring 2023)
- Election of President and Vice-President
- Report on activities on EU projects
- Annual Meeting for user community 2023

Technical Planning Group

11 February 2022 - A350 Concept Meeting

8 March 2022 - TPG Report 14

- Status of Operations: Package 1, Package 2
- Package 2: Certification and plans for deployment
- Planning and coordination of IAGOS-CORE aircraft installations
- Japanese GOSAT/China Airlines
- A350 Preliminary Study
- Airbus Aircraft: A350 MSN001, Beluga XL
- TPG members update

10 March 2022 – TPG Report to GA

- Current aircraft operations
- Package 2 STCs and strategy
- New aircraft planning
- Airbus Aircraft: A350 MSN001, Beluga XL
- IAGOS-CORE on A350

21 September 2022 – TPG/TOG Report at annual meeting

- Current aircraft operations
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- IAGOS-CARIBIC

15 November 2022 - TPG Report to GA

- Current aircraft operations
- Package 2 STCs and strategy
- New aircraft planning
- Airbus aircraft: A350 MSN001, Beluga XL

Advisory Board

14 November 2022

- Review of progress and planning
- Review of actions in response to recommendations made at last meeting
- Renewing and extending the fleet
- Tracking data availability
- Project map
- P1-P2 communications
- Social media

Technical Operations Group

Teleconferences

(01.2022, 03.2022, 09.2022)
The teleconferences cover the same four topics with additional points discussed when necessary.

1. Status of IAGOS-CORE operations P1, ICH, BCP, P2b, P2d on A340/330 aircraft
2. Status of Maintenance Centre Operations
3. Status of instrument certifications
4. Status of new aircraft installations

- Installation of IAGOS-CORE on Lufthansa D-AIKE A330
- Pre-study IAGOS-CORE on BELUGA XL
- Progress on the planned A330 Air Canada IAGOS-CORE installation
- Progress on IAGOS-CORE on AIRBUS A350 FLIGHT TEST msn1
- Progress on FZJ POPS on AIRBUS A350 FLIGHT TEST msn1
- P2b and P2d EASA STC transfer to other authorities (CAAD, FAA, TCCA)
- P2b and P2d on Air France A330
- Pre-study IAGOS-CORE on AIRBUS A350
- Part 145 MO LGM/SNT for P1
- FAA agreement for ACC COLUMBIA Jet Service GmbH - Support and Design
- P2e design and documentation finalization
- Discussions with CAL for new A330
- Discussions with IBERIA for new A330

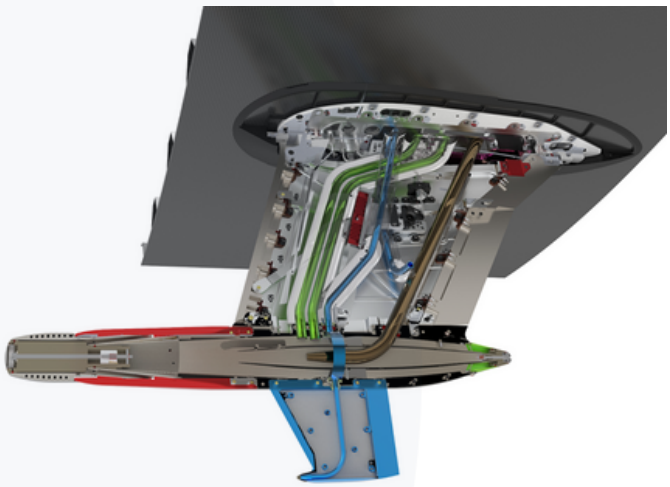
Activities of Members under Coordination of IAGOS-AISBL

IAGOS-CARIBIC

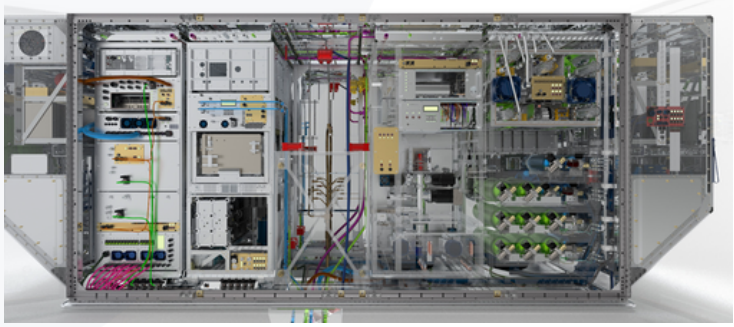
AIRBUS A350-900 "Erfurt" (D-AIXJ) at Lufthansa Technik Malta in March 2021 for Part 1 of the IAGOS-CARIBIC modifications (left) and the logos of all IAGOS-AISBL members, scientific and commercial partners involved in the IAGOS-CARIBIC A350 project.

After the premature phase-out of the IAGOS-CARIBIC A340-600 aircraft in April 2020 due to the COVID-19 pandemic, the modification of the Lufthansa AIRBUS A350-900 "Erfurt" (D-AIXJ) (above) has been started to operate the new IAGOS-CARIBIC container laboratory. It is a strongly modified air cargo container (LD6 with additional "ears" on the sides) that is equipped with state-of-the art instrumentation for in-situ measurements of trace gases and aerosol particles and for the collection of whole air and aerosol samples. The figure (right) shows a CAD view of the actual design with 16 considered instruments (status January 2023) .

On the A350 new features are implemented such as the satellite-based uplink of real-time measurement data to a ground-station, the standardised certification of scientific instrumentation to strongly accelerate the integration of new instruments (at correspondingly low price), the integration of new instruments or a new low-turbulent multi-function air inlet system (below) for aerosol particles of up to 10 microns, cloud particles, and the high-frequency measurement of temperature and pressure.



(above) New multi-function air inlet system for aerosol particles (red front part), cloud particles (blue fin), trace gases (green tubes) and a modified Rosemount system for temperature and pressure sensing.



(above)CAD drawing (partially transparent) of the new CARIBIC laboratory (width x height x depth = 406 x 162 x 153 cm, total weight: ~2.0 t), with the gas cylinder rack (right) and parts of the safety, communication and ventilation systems in the side compartments. The electrical and pneumatic connection to the A350 systems and the air inlet system occurs through the floor breakthrough in the middle section.

Activities 2022

In 2022, the CFD dynamical modelling and development of the air inlet system were finalised and its assembly has started (most of the works by enviscope). In parallel, the largely CAD-based construction of the new CARIBIC and the infrastructure systems (e.g. power supplies, pump unit, gas cylinder rack, ventilation and safety system, master control computer) were continued and partially finalised.

The 12 CARIBIC partners from Europe (Germany, Ireland, France) and the US modified existing instruments and developed/assembled new instruments, the table below.
A considerable fraction of the activities was dedicated to the airworthiness certification, that is, the planning with the involved companies (primarily enviscope, Lufthansa Technik, Lufthansa, Safran, ACC Columbia, Apsys, and Dynatec) and the preparation of the required documents.

#	Instrument	Institution	Species	Type	parameter	new	Status
1	CO	KIT	CO	in-situ	trace gas		√
2	O_3	KIT	O_3 (0.25 Hz, 5Hz)	in-situ	trace gas		√
3	PTRMS	KIT	VOCs (~5/min)	in-situ	trace gas		√
4	UMAQS	KIT & University Mainz	N_2O, CH_4, CO, C_2H_6	in-situ	trace gas	new	√
5	VOCUS	MPI-C, KIT	VOCs (>20/sec)	in-situ	trace gas	new	later
6	NO_y	DLR	NO, NO_y	in-situ	trace gas		√
7	Picarro	MPI-BGC	CO_2, CH_4	in-situ	trace gas		√
8	CARDINO	Uni. Cork, NOAA, KIT	NO_2, NO_3, N_2O_5, O_3	in-situ	trace gas	new	√
9	FunMass	FZJ (IEK-7)	SO_2, HCN, some acids	in-situ	trace gas	new	√
10	HIRES	MPI-C & University Frankfurt	N_2O, CH_4, CO_2, SF_6, NMHC, HCs	lab	trace gas		√
11	WIBS	MPI-C	Bacteria, funghi, pollen	in-situ	aerosol		√
12	SP2	MPI-C	soot	in-situ	aerosol		√
13	AMS	MPI-C & TROPOS	Aerosol composition	in-situ	aerosol		√
14	OPSS	TROPOS	Aerosol size distribution	in-situ	aerosol		√
15	Core-slot1	FZJ (IEK-8)	aerosol particle number and size distribution (organic and inorganic)	in-situ	aerosol		√
16	Core-slot2	FZJ (IEK-8)	aerosol extinction	in-situ	aerosol	new	√
17	PNC	TROPOS	aerosol particle number concentration	in-situ	aerosol	new	later
18	HERA	TROPOS	Ice nuclei	lab	aerosol	new	later
19	H_2O	KIT	H_2O, cloud water/ice content	in-situ	water/cloud		√
20	OFCEAS	University Grenoble, KIT	H/D, $^{16}O/^{18}O$ in H_2O and clouds	in-situ	water/cloud	new	later

table 1. Instrumentation of the new IAGOS-CARIBIC payload on the Lufthansa Airbus A350. Some instruments will be integrated delayed (last column). Seven new instruments are planned (second last column).

KIT coordinated and operated IAGOS-CARIBIC from April 2015, until March 2020 on the Lufthansa Airbus A340-600 "Leverkusen" (D-AIHE). Since then, KIT put all efforts into bringing the next generation of IAGOS-CARIBIC on the new Lufthansa Airbus A350-900.

Furthermore, KIT is responsible for four instruments (for ozone, water vapour, cloud water/ice, and organic compounds, VOCs) and is currently involved in the development of another three instruments (see table), e.g. a dual quantum cascade laser system by Aerodyne Research that allows high precision and high frequency (>1 Hz) measurements of nitrous oxide, methane, carbon monoxide, and ethane (together with the university Mainz) or a two-channel laser spectrometer (OF-CEAS) for the stable isotopologues in water vapour and cloud particles (together with the university Grenoble). All data are of high relevance for the new German DFG funded Collaborative Research Centre "TPChange" (The Tropopause Region in a Changing Atmosphere) in which several IAGOS researchers are involved.

Activities of Members

MPI-C will maintain the operation of 4 instruments (see table 1) and is responsible for the transfer of the whole air sampling systems (HIRES) in collaboration with University Frankfurt, a single particle soot photometer (SP2), a bio-aerosol analyser (WIBS) and an aerosol mass spectrometer (AMS) on the new A350 platform. For this, modifications of the flow systems and power supplies of the instruments were necessary. These modifications are nearly completed. The time having the AMS in their laboratory was used by MPI-C to continue their work on improving performance and characterisation of this instrument.

Beside the work on the modification of the instruments, MPI-C has to maintain in the laboratory three GC systems for greenhouse gases, non-methane-hydrocarbons and further N-and S-containing species that are used for measuring the altogether 88 air samples collected by HIRES during one flight sequence.

DLR is responsible for the operation of the NOy instrument (Table 1, #6) measuring nitrogen oxide (NO) and total odd nitrogen (NOy) in the CARIBIC container-lab. The data gained on the Airbus A340-600 until it was taken out of service in April 2020 was evaluated and made available for the database.

The certification and the resulting mandatory modification of the NOy instrument for the changeover to the A350 is very complex, because it was not possible to certify gas bottles containing pure oxygen on the new A350 platform due to much stricter regulations than for the A340 platform in 2004. This means that pure oxygen will be substituted by Heliox (21% oxygen in helium). Initial tests revealed a loss of sensitivity of the instrument. While the total reactive nitrogen measurement is not expected to be significantly affected, the detection limit for NO may increase. This needs to be further tested and optimised. Furthermore, since the measurement system is being rebuilt. Design, size and weight is being modified for future use on an Airbus A350.

TROPOS is responsible for the instruments measuring small particles (PNC), the particle size distribution (OPSS) and (in cooperation with MPI-C) the chemical particle composition (AMS) (see Table 1). In the first step, TROPOS will modify the OPSS instrument for the transfer to the A350. In parallel, TROPOS will develop a new PNC instrument, which will not use butanol anymore, and a IAGOS-CARIBIC version of the aerosol particle filter sampler HERA that is targeted for post-flight analysis of ice nucleating particles (INP). In the second step, both instruments will be integrated in the IAGOS-CARIBIC Container-Lab, ideally together with other instruments that could not be finalised in the first step (see instruments status Table 1).

FZJ is responsible for the IAGOS-CORE package-2 (P2) instrument slot in the CARIBIC Container-Lab, integrated in 2017. In the new A350 Container-Lab, there will be integrated a second IAGOS-CORE P2 instrument slot. Planned instruments to be deployed are one instrument for measuring key aerosol parameters, such as particle number concentration (PNC) for total aerosol and non-volatile particles as indicator for the mixing status of the aerosol, and particle size distribution (PSD). The instrument is similar to the instrument operated on the previous Container-Lab but now equipped with a non-flammable operation liquid appropriate for operation on aircraft, and one instrument for the measurement of air quality parameters NO_2 and aerosol parameters such as the aerosol light extinction coefficient as proxy for particulate matter mass concentration, particle number concentration and particle size distribution.

On top of this, FZJ will bring in a new highly sophisticated aircraft mass spectrometer instrument (FunMass). FunMass has been previously deployed on research aircraft and it is now modified for the deployment in the CARIBIC Container-Lab. FunMass is a very versatile instrument (Table 1) that can measure many reactive trace gases, and that will fill a long-lasting observational gap in IAGOS-CARIBIC – SO_2 measurements.

MPI-BGC is responsible for the Picarro CRDS carbon dioxide and methane measurement system. MPI-BGC has continued to design the modification instrument for the changeover to the A350 platform. These modifications are mainly related to the new power supply (270 VDC), communication and front plate connector standards in the new Container-Lab.

IAGOS-CORE

IAGOS cooperates with several airlines for quasi-continuous measurements of trace gases, aerosol and cloud particles from a fleet of long-haul passenger aircraft. Each aircraft carries the IAGOS-CORE rack with provisions for installing fully automated instruments measuring ozone, carbon monoxide, humidity and cloud particles (denoted P1), and provisions for installing a second instrument package (denoted P2) for measurements of either total odd nitrogen (P2a) or nitrogen oxides (P2b) or aerosol (P2c) or greenhouse gases (P2d) or air quality as NO_2 and Aerosol Extinction parameter (P2e). A special plate with dedicated inlet probes for the different instruments is mounted on the fuselage in the vicinity of the rack. The seven aircraft shown (next page) are currently equipped with the IAGOS-CORE Rack and P1. Package 2b is flying on Lufthansa D-AIGT. One Package 2d is flying on D-AIKO.

Instrumentation

Installation and operation on commercial aircraft requires that IAGOS instruments are fully compliant with design standards, safety regulations, and quality management of civil aviation. The aircraft modification has been approved by the European Aviation Safety Agency (EASA) as a Supplemental Type Certificate (STC), which was issued in 2011 for A340 and in 2013 for A330 aircraft. For installation in countries outside the EU, the EASA-STC has to be adopted by the national authorities responsible for the airline of concern. This process was successfully completed in 2012 for Taiwan (China Airlines), in 2013 for Hong Kong (Cathay Pacific), and in 2018 for the USA (Hawaiian Airlines). Each new aircraft to be equipped with the IAGOS modification must be investigated for compliance with the technical requirements of the IAGOS installation in terms of structure, electrical load and safety.

The P2b and the P2d instruments now have an EASA-STC. It is planned to extend this EASA-STC for the other aviation authorities such that the instruments can be installed successively on all IAGOS-CORE aircraft.

IAGOS-CORE Fleet in 2022.

Activities 2022

The Members involved in IAGOS-CORE, Forschungszentrum Jülich (**FZJ**), Centre National de la Recherche Scientifique (**CNRS**), Max-Planck Gesellschaft zur Förderung der Wissenschaften (**MPG**), Météo France (**MF**), and The University of Manchester (**UMAN**), concluded the following tasks:

FZJ acts together with CNRS as one of the leading institutions in operating the Research Infrastructure. Its Institute of Energy and Climate Research - 8 Troposphere coordinates the German contributions to the European Research Infrastructure and ensures smooth operation of the IAGOS Maintenance Center (IMC), the latter in close collaboration with the company enviscope GmbH which operates the IMC. FZJ IEK-8 coordinates the IAGOS Technical Operations Group and the Data Quality Assurance and Quality Control (QA/QC) activities. Together with CNRS, FZJ is responsible for the close contact to the participating airlines, including contract management and installations of IAGOS equipment on aircraft.

FZJ is further responsible for the maintenance, operation and data production from scientific instrumentation for the measurement of relative humidity over ice, water vapour and nitrogen oxides on IAGOS-CORE and aerosol particles on IAGOS-CARIBIC. Particular focus is put on the implementation and commissioning of a novel instrument for the measurement of key air quality parameters NO2 and particulate matter (PM).

FZJ also serves as the coordinator for the EU H2020 project ENVRI-FAIR (Environmental Research Infrastructures building FAIR services accessible for society, innovation and research; www.envri-fair.eu) which is funded under Grant Agreement No 824068. ENVRI-FAIR targets the development and implementation of both technical frameworks and policy solutions that prepare Earth system science for the new Open Science paradigm, based on FAIR-compliant data services. In this context, FZJ is operating fully automated and scalable data management and QA(QC workflows for the IAGOS instrumentation on water vapour/RHice, NOx and greenhouse gases, the latter in close collaboration with MPI-BGC.

FZJ maintains its strong engagement in the scientific analysis of the data set from its own resources. As in the past for MOZAIC, this is achieved through close collaborations with leading universities and instrument manufacturers, particularly on the topics of upper tropospheric water vapour distribution, cirrus clouds, aerosols and chemical composition in general.

FZJ coordinates together with KIT the collaboration with the joint research project TPChange (The Tropopause Region in a Changing Atmosphere; https://tpchange.de/) of the German Research Council DFG. FZJ is also engaged in the Copernicus Atmosphere Monitoring Service.

In the reporting period 2022, FZJ focused on the provision of Level 2 water vapour data from 2011 to 2022 for scientific analyses. The reanalysis and harmonisation of L2 water vapour data for the entire IAGOS period starting in 2011 was necessary because of data transmission problems. The difficulties were resolved and the L2 water vapour data were released for scientific use at the end of 2022. From German resources, the installation of IAGOS equipment on the 3rd aircraft of Deutsche Lufthansa/ Eurowings Discover was finalised and the certification of the various Package 2 types was further advanced, with the STC being received for the NOx instrument (P2b). Major progress was achieved in the field of instrument development, near real time data transmission, and data analysis. The implemented automated data inversion algorithm for water vapour permits the operational provision of data in NRT mode to the IAGOS data database; this algorithm was generalised for broader application to all IAGOS instrumentation and redesigned in compliance with the FAIR principles. By the end of 2021, this data production chain was operational for NOx and greenhouse gas data, with the adaptation to water vapour data being in progress for 2023.

The novel Package 2 instrument of type P2e (Air Quality package) for the simultaneous detection of aerosol and NO2 passed successfully all qualification tests and is ready for certification. The detailed scientific qualification of all instrument components in the laboratory was successfully finalised in the framework of an ongoing PhD study and submitted for publication.

Two full years of operation of the IAGOS-CORE aerosol package on IAGOS – CARIBIC provided excellent data which are currently exploited for novel insights on the climate impact of aviation and the impact of volcanic eruptions on the aerosol of the lowermost stratosphere. Respective scientific publications are prepared for the year 2023.

Together with its longstanding partners Deutsche Lufthansa/Lufthansa Technik and *enviscope* GmbH, FZJ coordinated the feasibility study on the transfer of the IAGOS-CORE system to the new platform Airbus A350-900. The feasibility study sets the framework for the installation of measuring devices on the new platform, specifies the technically necessary steps and quantifies the costs to be expected. FZJ is preparing the next step towards the realisation of the system transfer to the A350.

In the framework of the European research project ACACIA (Advancing the Science for Aviation and Climate; https://www.acacia-project.eu/) FZJ conducts analyses of the IAGOS-CORE and IAGOS-CARIBIC data sets combined with the data set of the Juelich In-situ Airborne database (JULIA) to investigate the occurrence conditions of long-living contrails and resulting aviation-induced cloudiness as well as aviation-induced aerosol particles in the upper troposphere. Both studies are key contributions to the ACACIA key objectives of reducing the uncertainties regarding the impact of aviation soot particles on natural cirrus clouds, identifying occurrence patterns of aviation-induced cloudiness to assess the radiative forcing of contrail cirrus, and improving the estimates of aviation aerosol effects on low-level clouds. Respective publications have been finalised and submitted in 2022 (aviation-induced cloudiness), or are progressing for publication in 2023 (impact of aviation soot particles).

Together with CNRS, FZJ is also contributing significantly to the European research project RI-URBANs with air quality observations and the generation of respective data services.

CNRS acts, together with FZJ, as one of the leading institutions in operating the Research Infrastructure. Laboratoire d'Aérologie (LAERO), UMR5560, of CNRS coordinates the technical and legal work in France, and with the main partners from other countries, particularly FZJ in Germany, assumes responsibility for establishing contracts with airlines and maintenance organisations in order to ensure the timely progression of the work. CNRS acts as the leading French partner in cooperation with partners in Germany and U.K., on aircraft modification, including the acquisition of the IAGOS modification kits. CNRS ensures the performance, sustainable operation and data quality of the ozone and CO instruments by pre- and post-calibration procedures in its laboratory. CNRS also ensures the coordination of the IAGOS Data Centre in close collaboration with the French data centre AERIS (http://www.aeris-data.fr).

CNRS coordinates IAGOS-FR (CNRS and MF), the national Research Infrastructure of the French Ministry for Higher Education, Research and Innovation (MESRI), which is the French contribution to IAGOS. In France, 2022 marks the beginning of the OBS4CLIM Equipex project pursuing the objectives of upgrading and innovating the IAGOS fleet and its automatic instruments, in collaboration with the French components of ICOS and ACTRIS.

CNRS maintains its strong engagement in the scientific analysis of the dataset from its own resources. Since the beginning of MOZAIC, this has been achieved through data analysis and modelling activities in collaboration with data users worldwide. CNRS is also engaged in the Copernicus Atmosphere Monitoring Service, in particular for the validation of the regional and global models. Since 2019, this validation has also included the water vapour, and very recently carbon dioxide and methane, as data are available in NRT. See the dedicated pages in http://www.iagos-data.fr/cams and in the highlights section above.

In the reporting period 2022, as planned, CNRS financed one kit of installation and several maintenance kits to adapt the system to the new maintenance process in France which is now performed by LGM and Sabena. 2022 was just like 2021 in many aspects and the different activities have been difficult or very long to handle.

A major part of the activities concerned the finalisation of the maintenance process and the operation of the equipment (including the acquisition system and transmissions) aboard the three Lufthansa Group IAGOS-CORE aircraft. Despite the long-lasting COVID-19 difficulties, CNRS activities included logistics, maintenance, quality assurance of the ozone and carbon monoxide data, and provision of the data and metadata to the IAGOS database. CNRS also aims to deliver the data in near real time (NRT) to ECMWF for the CAMS thanks to the development of software for data analysis, quality assurance for faster validation, and availability. CNRS continues this engagement in Copernicus through the phase 2 of Copernicus (until 2028). Indeed, from 2022 on, CNRS is still a sub-contractor of KNMI in the CAMS2-82 and CAMS2-83 contracts, which focus on the evaluation of regional and global models with ozone, CO, and water vapour data, as well as greenhouse gases. Even with a lower amount of recorded data, CNRS continued to produce periodical reports for CAMS.

Development of the database in 2022 included the continuous improvement of the database and reception servers in Toulouse. The provision of added-value products produced with SOFT-IO, such as meteorological information and air-mass history are continuous efforts in addition to the improvement of the data workflow with automation, integration of new QA/QC metadata, and flight comparisons. In 2022, major improvements have been followed up thanks to resources and expertise gained through the ENVRI-FAIR (started in January 2019; with the Atmospheric domain being co-led by CNRS as IAGOS Member), and ATMO-ACCESS (started in April 2021; with CNRS as IAGOS Member leading one of the task on the data analysis and on-line plotting) projects. Colocation tools and data visualisation for users, as well as the contribution to the Environmental Dashboard for EOSC are highlight products to be followed/enhanced in the coming years. The RI-Urbans project (started in October 2021; with CNRS and FZJ as IAGOS Members) has led to new developments for new services dedicated to urban air quality in several pilot cities including Paris and Amsterdam-Rotterdam. This is the rationale for installing the P2b on the A330 from Air France as soon as possible and to envisage adding a KLM aircraft to the IAGOS fleet. It is finally worth mentioning that the KADI project started in October 2022 under the coordination of ICOS. CNRS as IAGOS Member, will contribute to the ultimate aim of this project which is to design a pan-African climate observation research infrastructure.

The Institute of Biogeochemistry (MPI-BCG) of MPG is responsible for the operation of instruments for the measurement of greenhouse gases (GHGs), namely carbon dioxide and methane , as well as carbon monoxide and water vapour. The instrument is referred to as Package 2d (P2d). It has obtained approval by the European Aviation Safety Agency (EASA) for deployment aboard passenger aircraft as part of the IAGOS-CORE installation.

The first Package 2d (SN01) was operated onboard the Lufthansa A330 aircraft (tail sign D-AIKO) during an extended deployment phase from 20 Jul. 2021 to 11 May 2022 with 257 flights. High quality data was retrieved from about 60% of the flights, while for the rest of the flights the data transmission via GSM was not working reliably. The exchange of calibration gas cylinders was made during the deployment periods.

During the deployment period in 2022, GHG data have been acquired from a total of 52 flights. In-flight calibration results assure traceability of carbon dioxide, methane and carbon monoxide data to WMO calibration scales. Degradation of optical components inside the cavity (where the sample gas is analysed) caused the data quality to deteriorate, resulting in complete failure after March. Processing of final level 2 P2d data is in progress, as the lower data quality results in a large number of additional processing steps.

The discovery of a degradation was confirmed by the manufacturer of the P2d components (picarro, Inc.), who stated that according to recent experience the lifetime is in the range of 7-14 years (which is the age of the P2d components). In addition there is a backlog of optical components due to supply chain issues. The result is a shortage of cavities, causing a delay in the completion of assembly of all six P2d systems. Currently, two P2d systems are ready for deployment (SN03 and SN04), SN01 is being modified to Rev. 2 status to comply with the current STC, and SN02 is in maintenance with a repaired cavity. For completion of SN05 and SN06 further cavities have to be acquired as their original cavities have been used in the other systems. This now allows installation of further P2d systems on other airlines besides Lufthansa, the next being China Airlines.

In 2022, the responsibilities of **Météo France** have been to maintain the links between the numerical weather prediction services particularly with respect to Environment Canada, and secondly to maintain the links with the upper air observations of the World Meteorological Organisation.

UMAN is responsible for operation of the Backscatter Cloud Probe (BCP) aboard all IAGOS-CORE aircraft. The BCP is a new instrument, originally designed as simple cloud detector, which still requires substantial work for characterisation of its performance with regard to analysing the size distribution of cloud particles.

UMAN is working with the supplier (DMT) to deliver improvements to BCP integrity and to improve and extend the operational characteristics and lifetime of the BCP. It is becoming apparent that the older BCPs are now starting to show deterioration, exposed as they are to extreme conditions on the outer fuselage. We have been working with enviscope to improve care and maintenance of these older instruments. Certification for the newer BCP-H versions has been completed and gradual replacement of the older instruments is underway.

A new multi-calibration system was funded ($80k), called the Universal Cloud Simulator (UCS), manufactured by Cloud Measurement Solutions, USA, and delivered March 2023. Designed specifically for the BCP-H it can also be used for proposed future BCP replacements including BCP-DPOL, being considered for installation on the Airbus Test Aircraft. The new BCP-DPOL will deliver higher resolution cloud/data sets able to discriminate particles according to water and ice phase. The new calibration data sets will also allow improvements to standard BCP data products, speed up on-site calibration to reduce costs, and to better quantify instrument to instrument variation whilst providing common calibration data sets with new research aircraft cloud instrument databases.

The recently funded UKRI NCAS upgrade to the FAAM Aircraft will include two new BCP-DOL sensors. Manchester will work with FAAM and CMS to calibrate and characterise these with the UCS system being developed. Manchester have just been awarded £2.1M for new wing-borne cloud instruments for the FAAM aircraft (supplied by SPEC USA and Schnaitec Germany) which will be used as reference standards to compare the BCP-DPOL data products with for eventual delivery of BCP-DPOL data products as part of the core FAAM data. This programme starts in April 2023.

The agreement with FAAM-NCAS to provide support for the BCP-D routine data as part of NCAS funding for IAGOS has been renewed for 2023. and it is currently offered as part of the FAAM core cloud instrument fit for facility users. NCAS and NERC have recently funded (Jan 2020) the Manchester MU-HOLO project to develop two new high-resolution holographic spectrometers in collaboration with the University of Mainz, one for the FAAM aircraft and one for use in the Manchester laboratory cloud calibration facility which can be used for validation of BCP ice particle retrievals. Agreement to deliver FAAM BCP/D and complementary data products data via the CEDA data portal will be discussed at upcoming FAAM-NCAS cloud instrument strategy meetings.

A full time NCAS cloud instrument post has now been advertised at Manchester (Jan 2023). The post will be funded for the next 3 years and responsibilities will include assistance to the NCAS funded IAGOS data scientist, Dr. G. Lloyd, for laboratory calibration of the IAGOS BCPs, BCP-DPOLs and further development of the UCS calibration system.

A new BCP-H was also funded by NCAS ($83k) for the proposed Air Canada IAGOS aircraft and installation will take place in 2023. .

IAGOS Maintenance Centre

The company *enviscope* GmbH is in charge of the maintenance and aeronautical management of the instruments operated on board of civil aircraft. Instrument calibration is conducted at the laboratories of the scientific partners while *enviscope* is responsible for the coordination of the calibration activities and for the quality assurance related to continued airworthiness of the equipment. The company is involved in IAGOS since the beginning with respect to instrument development and aeronautical certification. Hence, in-depth knowledge of deployed techniques and aeronautical procedures is ensured.

Activities in the reporting period covered the following issues:
(i) maintenance of Maintenance Centre Website for interactive usability including connection with enviscope data base;
(ii) improvements of data base to handle logistics and documentation;
(iii) logistics like instrument storage and shipment (see Table 2), and handling of instrument exchange intervals (even under COVID conditions);
(iv) instrument maintenance, repair, overhaul, servicing, testing and parts production;
(v) checking logistics alternatives for shipments to Hawaiian Airlines;
(vi) instrument and spare part distribution to airlines;
(vii) coordination activities for approving legal aviation requirements;
(viii) participation in the IAGOS Technical Operations Group and Technical Planning Group, including the organisation of teleconferences and using redmine tool;
(ix) communication with airlines (especially with China Airlines to prepare Package2 implementation);
(x) update of internal procedures to adapt to ACC Columbia Jet Service (ACJ) quality management system;
(xi) audit by LBA without findings;
(xii) trainings in order to keep enviscope being a station of ACJ for production and maintenance;
(xiii) enviscope personnel trained as certifying staff of ACJ and can issue dual release EASA Form1 (TCCA, FAA will follow early in 2023) as repair station for all IAGOS components (despite of Package1 unit and pump box). Certifying staff planned to extend from 4 to 7 employees;
(xiv) organizing transfer of Package2 STCs to CAA for implementation on 2 China Airlines Aircraft in 2023.

In addition, *enviscope* supported to apply a minor change of STC for Package2b and Package2d. *enviscope* develops, manufactures and qualifies a Package2e prototype, and prepares certification documentation. The IMC stayed fully operational and is unaffected by COVID due to adaptation of the working environment.

Item	Member					Airline				
	FZJ	CNRS	UMAN	MPG	other	DLH	CAL	CPA	AFR	HAL
Package 1		10				2	1		1	1
Package 2ab	5	2				2				
O_2/HelOx/SynAir	26				9	10				
Pump Box		10				3	1		1	1
BCP	2		1		1	3	1		1	1
ICH	45					15	1		4	2
Package 2d				1		1				
AIR				18						
Auxiliary parts	3	3		2	16	6	4			2

Table 2: Shipments of instruments and auxiliary parts for IAGOS-CORE operation in 2022

Financial Information

Balance 2022

Income	
Membership Fees	130,000€
Total Income	**130,000€**
Expenditure	
Personnel incl. overheads	56,423€
Services and other expenses	91,026€
Total Expenditure	**147,449€**
Amount carried forward from 2022	**200,790€**
Total Balance December 2022	**183,341€**

Resources dedicated to IAGOS by the Members

In 2022, the Members contributed in total approximately 6.5 Million Euros from own resources in the form of personnel, equipment and consumables to construction and operation of the IAGOS Research infrastructure according to the Statutes of IAGOS-AISBL. The breakdown of costs, calculated according to Article 22 of the Statues, is listed in Table 3.

Group	Operation & hardware (k€)	Personnel (k€)	Total (k€)
FZJ	870	1022	1892
CNRS	727	980	1708
MPG	330	453	783
MF	32	11	43
UMAN	92	121	213
DLR	131	80	211
TROPOS	78	54	131
KIT	766	711	1477
TOTAL	3025	3545	6458

Table 3: Contributions by the Members to construction and operation of the infrastructure from institutional resources and national funding[1]

[1] NOTES: Personnel costs are calculated based on the average salaries of FZJ and CNRS, including overheads (82.4%). Acquisition of hardware is included by 10% annual depreciation. Not included are Membership fees, funding from European projects, and work related to scientific activities.

Additional resources of approximately 472 k€ were deployed in 2022 due to co-funding by the European Union for projects ATMO-ACCESS, RI-URBANS, ENVRI-FAIR and contributions to the Copernicus Programme (CAMS2-82/83). In addition CNRS gets 50k€ from OBS4CLIM.

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Bundesministerium für Bildung und Forschung

Ministère de l'Enseignement Supérieur, de la Recherche et de l'Innovation

National Centre for Atmospheric Science
Natural Environment Research Council

AERIS

The participating Airlines contribute significantly to operation of the IAGOS infrastructure by waving the additional fuel costs incurred by carrying the IAGOS-CORE installation and by providing technical expertise during installation and deployment of the equipment.

AIRFRANCE
IBERIA
AIR CANADA
CHINA AIRLINES
HAWAIIAN AIRLINES
Eurowings discover.
Lufthansa
CATHAY PACIFIC

Peer-reviewed Publications

1. Chang, Kai-Lan, Owen R. Cooper, Audrey Gaudel, Marc Allaart, Gerard Ancellet, Hannah Clark, Sophie Godin-Beekmann, et al. "Impact of the COVID-19 Economic Downturn on Tropospheric Ozone Trends: An Uncertainty Weighted Data Synthesis for Quantifying Regional Anomalies Above Western North America and Europe." AGU Advances 3, no. 2 (2022). https://doi.org/10.1029/2021AV000542.
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4. Clark, H., IAGOS Aircraft Measurements in Africa, Advancing Air Quality and Carbon Science in Africa workshop (NCAR/UCAR), 10-12 March 2021.
5. Clark, H., The effects of the COVID-19 lockdowns on air-quality throughout the troposphere as seen by IAGOS in-situ data, 16th IGAC Scientific Conference, 2021.
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