Dear Colleagues and Friends of IAGOS,

The COVID-19 pandemic is affecting all of us, regardless of where we are or what we do. On behalf of the IAGOS-AISBL, I would like to acknowledge all the additional work to further foster the success of the Research Infrastructure IAGOS despite these challenging times.

IAGOS thanks all our partners, and especially the airlines, for the support that you have given us over the last year. We understand the economic difficulties that airlines and manufacturers are facing due to the coronavirus crisis and are particularly grateful of your support at this time. This has been very reassuring for IAGOS and has enabled us to continue to provide data to our users during this difficult global situation.

The World Meteorological Organization and the European Center for Medium Range Weather Forecast’s, European Copernicus Program, have highlighted the importance of data from aircraft in the global observing system, in assuring the accuracy of weather and air-quality forecasts, and in maintaining monitoring of our climate:


We are using this quieter period to move forward with extending IAGOS to the A350 in addition to the A330, and to prepare for the IAGOS container measurements on a specially modified A350.

The long-term continuous, global monitoring of climate change and air-quality throughout the troposphere and lower stratosphere is nowadays an even more important issue for society, for weather and air-quality forecasts, for scientific research and not least to help the aviation industry address new environmental challenges, in particular to meet requirements for environmental sustainability and corporate responsibility.

I am confident that together we will be able navigate these difficult times and that we will emerge even stronger. The IAGOS research infrastructure is always looking to expand aircraft measurements of atmospheric composition for the WMO’s Global Atmosphere Watch and ECMWF’s Copernicus Atmosphere Monitoring Service.

I wish all of us good health and good spirit.

Yours Sincerely

[Signature]
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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 which monitors the state of the Earth system and climate. It sets out how the IAGOS data has been used in regard to the ESFRI sustainable development goals and KPIs.

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 satellite data cannot achieve. Through ENVRI-FAIR, we endeavour to ensure that these data are freely and easily accessible and maintain FAIR data standards. Together with ICOS and ACTRIS, the two other RIs from the atmospheric domain, we are working on further harmonization of data products and services for the benefits of users. The new project ATMO-ACCESS (starting 1st April 2021 for 4 years), will deliver a series of recommendations for establishing a comprehensive and sustainable framework for access to distributed atmospheric Research Infrastructures. 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

COVID-19/difficulties: The COVID-19 crisis has been a difficult period for IAGOS and all our partners in the aviation industry as many aircraft have been grounded and passenger numbers and flights have seen a 70% drop. We hope that the recovery of international travel and the opening of national borders, will enable IAGOS to continue to provide unique and critical information as vertical profiles and real-time monitoring of air pollution over major urban locations to quantify the impact of emission changes pre, during, and post pandemic. These will have relevance to government emissions mitigation policies, the aviation green recovery, air pollution forecasting and validation, and improvement of global satellite remote sensing.

COVID-19/opportunity: The lockdowns provided a unique experiment to assess the impact of a reduction of economic activities on atmospheric composition and climate. The meteorological conditions were exceptional during the period of the first lockdown, and the IAGOS data highlight the importance of long and continuous time-series in setting this in context and to determine the significance of the event. Ozone was seen to increase at the surface to values not seen since the 2003 heatwave in Europe, and a decrease was observed in the free troposphere. Carbon monoxide showed a decrease throughout the troposphere.

Technology and measurements

The move of the CARIBIC cargo container to the A350 advanced significantly in 2020 precipitated by the retirement of the A340 CARIBIC aircraft due to the COVID-19 crisis. Over the summer we obtained carbon dioxide measurements and methane measurements from the optional greenhouse gas package (P2d) which is installed on D-AIKO.

Development and Expansion

Despite difficulties, this year 2020 has seen developments with potential new partners leading to an expansion of our network toward Eastern Asia (Taiwan, Japan with the possibility of a third aircraft from China Airlines), North America, and Western and Northern Europe. We are working to expand our network to climate sensitive regions, in particular the far northern latitudes which are warming twice as fast as elsewhere and where the harsh environment makes obtaining in situ measurements particularly challenging. It is important to maintain and reinforce our transatlantic network which has been the backbone of IAGOS over the last 25 years.

FAIR and Open Data: IAGOS, under the lead of Forschungszentrum Jülich, is coordinating the European ESFRI cluster project ENVRI-FAIR (Home ENVRI-FAIR – ENVRI Community) which is aiming towards easy and seamless access to research data and services from all domains 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 2020 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 internet presence.
IAGOS data are used to understand the budget and trends of tropospheric ozone. Benefitting from the 2 flights a day made by China Airlines from Taipei during the typhoon season of 2016, Roux et al. (2020) found that air is charged with ozone before the arrival of a typhoon, related to the descent of stratospheric air. After, typhoons bring clean and unpolluted air from the marine boundary layer. Tropical cyclones participate in stratosphere troposphere transport. This transport could be a regular feature of typhoons, and therefore be important in the budget of ozone in the upper troposphere. Gaudel et al. (2020) used IAGOS data to show that ozone increased in the northern hemisphere despite the reduction of the emissions of nitrogen oxides in midlatitudes. Building upon the tropospheric ozone assessment report, Cooper et al. (2020) compared ozone trends at remote surface sites with IAGOS profiles above northwestern Europe. In Corwin and Banyard (2020) the 25 years of meteorological fields from IAGOS were exploited to examine gravity waves in the upper troposphere-lower stratosphere in the region of the jet stream. This article was the first example of the meteorological data from IAGOS being exploited.

**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-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. We worked on the submission of a project on urban air quality (RI-URBANS) for the European Green Deal for assessment and improvement of urban air quality models. The IAGOS data over Hawaii was used in a publication by the U.S. Environmental Protection Agency in the development of a meteorological and air quality modeling for Hawaii, Puerto Rico, and the Virgin Islands (Baker et al., 2020).

**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 Organization. We are ensuring that our data meets the FAIR criteria and are coordinating the ENVRI-FAIR project. **Aviation Industry:** As the airlines and the aviation industry try to recover from the COVID-19 crisis, IAGOS can play an important role in helping them to develop along a more environmentally sustainable path. We participate in European projects on the impact of aviation on climate such as the project ACACIA.

We also work with aircraft and engine manufacturers on projects that aim to improve engine performance (Sand & Dust Threats to Aircraft Engines) and on issues relevant to aviation safety such as icing. In the special issue on “Weather and Aviation Safety” Lloyd et al. (2020) used the back-scatter cloud probe to examine the prevalence of ice-clouds on a global scale. Ice crystal ingestion by jet engines, which is a potential safety consideration for aircraft operations.

Related to this, fifteen years of IAGOS data also revealed the global scale of ice supersaturation in the northern mid latitudes showing no discernable trend in upper troposphere relative humidity over the North Atlantic (Petzold et al. 2020). The special issue of the journal Aerospace pertaining to the 3rd ECATS Conference on Making Aviation Environmentally Sustainable, used the relative humidity data from IAGOS to assess how well persistent contrails can be predicted (Gierens et al 2020).

In a new and interesting application of IAGOS data to the aviation industry, Li and Cotton (2020) used IAGOS data to calculate the probability of condensation on electrical wiring within aircraft systems. When systems are operated in the aerospace environment, the ambient temperature, relative humidity and air pressure all vary with altitude. There is a risk of condensation on insulating material, such that a conductive path can form on the insulating surface. This is known as “tracking” and is of increasing relevance in More Electric Aircraft (MEA).
Key Performance Indicators (KPIs)

We implement these KPIs for the first time in 2020. The KPIs are based on the 10 chosen KPIs from the list of 21 proposed by ESFRI.

<table>
<thead>
<tr>
<th>KPIs in 2020</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of new users served</td>
<td>99</td>
</tr>
<tr>
<td>Number of publications</td>
<td>14</td>
</tr>
<tr>
<td>Number of new MSc and PhD students using the RI</td>
<td>38</td>
</tr>
<tr>
<td>Number of Members of the RI from ESFRI countries</td>
<td>8</td>
</tr>
<tr>
<td>Share of users and publications per ESFRI member country</td>
<td>50%</td>
</tr>
<tr>
<td>Outreach through media</td>
<td></td>
</tr>
<tr>
<td>Outreach via the RI’s own web and social media</td>
<td>93 new Twitter users</td>
</tr>
<tr>
<td></td>
<td>2230 Twitter profile visits</td>
</tr>
<tr>
<td></td>
<td>87 YouTube views</td>
</tr>
<tr>
<td>Participation by RIs in policy related activities</td>
<td>ESFRI science cluster</td>
</tr>
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<td></td>
<td>ESFRI-EOSC workshops</td>
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<td></td>
<td>ESFRI Task-Force</td>
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<tr>
<td></td>
<td>Board of European Environmental Research Infrastructures</td>
</tr>
<tr>
<td>Share of users and publications per non-ESFRI member country</td>
<td>40%</td>
</tr>
<tr>
<td>Extent of operational resources and investments made available in 2020 (operational costs)</td>
<td>7274k€ (+17% c.f. &lt;2015-2019&gt;)</td>
</tr>
</tbody>
</table>
The World Health Organization declared the global COVID-19 pandemic in March 2020 (WHO, 2020). The serious threat to public health led countries to adopt lockdowns and other coordinated restrictive measures aimed at slowing the spread of the virus. These measures had an important effect on economic activity and by consequence on the emissions of primary pollutants from industrial and transport sectors. Many of our partner airlines were forced to ground their fleets due to a fall in passenger numbers and the imposed travel restrictions. Fortunately, Deutsche Lufthansa was able to maintain the 26 year time-series of measurements at Frankfurt airport by modifying one of the IAGOS passenger aircraft for cargo. The continuation of the measurements at Frankfurt is important so that the atmospheric changes induced by the pandemic can be set in the longer context.

The level of primary pollutants such as NO, were observed, from satellites and from ground-based air-quality networks, to have fallen during the lockdowns across China and across Europe. The IAGOS measurements of the primary pollutant and ozone precursor carbon monoxide was lower than the long term average and fell outside the envelope of interannual variability. The largest reduction of 18% was seen at the surface (up to 600m altitude). The observed anomalies were significant with respect to the 18-year time series but are difficult to associate with the effects of lockdown, due to the exceptional meteorological conditions, the well established negative trend of CO, and the interannual variability.

In the free troposphere, there was a 2% reduction, and in the upper troposphere, there was virtually no anomaly. The small change in the background values of CO, highlight the important role of regional transport of CO from all sources and suggest that the lockdown measures did not have a big impact on background CO.

The secondary pollutant ozone, was seen to increase in the layer closest to the surface (up to 600m altitude) and thereafter to decrease. We noted a 24% increase in ozone at the surface (~950hPa, ~600m) which is greater than any other anomaly in springtime since the time series began 1994. The reasons for this increase are due to the complex ozone chemistry. The reduction in emissions of NOx led to less loss of ozone during the nighttime, while during the daytime, photochemical production of ozone was increased due to the exceptionally sunny weather and clear skies. In the free troposphere, ozone amounts fell, and this is more indicative of background levels being reduced regionally due to the lockdown measures. The lockdowns provided a unique experiment to assess the impact of a reduction of economic activities on atmospheric composition and climate. The meteorological conditions were exceptional in the period, and the IAGOS data highlight the importance of long and continuous time-series in setting this brief period in context and to determine the significance of the event.

## Highlights

The IAGOS data highlight the importance of long and continuous time-series in setting this brief period in context and to determine the significance of the event.

IAGOS observations of ozone for March-April-May 2020 in black. The left panel shows ozone and the right panel shows carbon monoxide. The red (blue) line is the average profile of CO (ozone) for MAM calculated over the time-series observations 2016-2019 for CO and 1994-2019 for ozone. The shaded areas represent the interannual variability over these reference periods.
IAGOS-CARIBIC on the Lufthansa A350-900

With the premature phase-out of the IAGOS-CARIBIC A340-600 in April 2020 due to the COVID-19 pandemic, the efforts for modifying a Lufthansa A350-900, which began more than two years ago, were further intensified. The main players are Safran Engineering (as STC applicant and responsible for the EASA certification), enviscope (design organisation and interface between the scientific institutions and Safran), and KIT (as IAGOS-CARIBIC coordinator and responsible for the CARIBIC container infrastructure). A number of further companies are in charge of designing and implementing the fuselage breakthrough (including the reinforcements, qualification, and laboratory tests), for the computational fluid dynamics (CFD) calculations for designing and optimizing the fairly complex air intake system or for helping with the elaborate system safety analysis. The STC application was submitted on 3rd July 2020 and the kick-off meeting with EASA took place on 5th August 2020. Since then, the concepts as well as the design for the modification of the A350 and for the new CARIBIC laboratory have continuously been further elaborated in close collaboration with EASA until the preliminary design review (PDR) in November 2020 and the critical design review (CDR) in January 2021 for the modifications of the A350.

The A350 modification will occur in three steps: Part 1 on 15-29th March 2021 at Malta, by far the most complex and time-consuming step. Here the fuselage breakthrough (including all structural reinforcements) and almost all aircraft modifications will be done, e.g. the electrical and pneumatic container interface panel installed, the air sampling system to the container interface panel, the entire wiring including ARINC interface box, and all CARIBIC-specific safety installations required as part of the aircraft. In Part 2, the air intake system (not available yet and expected for autumn 2021) will be installed for a test flight (where effects regarding vibration, buffeting, electromagnetic interference etc. will be tested). After a 4-6 week evaluation phase and final certification by the EASA, the air intake system will be permanently installed in Part 3 of the modification. Then the new CARIBIC laboratory with a strongly modified payload will be installed and tested regarding negligible interference with the aircraft systems. If all works well, the full EASA certification can be foreseen by December 2021 after which the usual IAGOS-CARIBIC operations can restart. As only a subset of instruments (around 12-14) can be certified in this first modification phase, a shorter flight pause of ~8 weeks for integrating the remaining instruments and a further laboratory EMI test is expected for the end of 2022.

The converted A350-900. The arrow marks the position of the air inlet system.
The new-look website was launched in September 2020. It will soon be linked with the new interactive tools for exploring the IAGOS database.

All data will be made available through the IAGOS database once the system has undergone a post deployment calibration and system check, planned for early 2021.

IAGOS Greenhouse gas measurements with Package 2d-SN01 started in an operational mode in 2020, acquiring high quality data on more than 90 flights with the Lufthansa Airbus A330 (tail sign D-AIKO). Typically, the aircraft serves airports in North America and the Middle East. Related to the COVID-19 pandemic, during April and May 2020 the aircraft was used to carry cargo, performing frequent flights between Frankfurt, Incheon (South Korea) and Shanghai (China). As an example, measurements from 2d data during a flight to Incheon are shown in the figure, showing excellent performance throughout the flight.

All data will be made available through the IAGOS database once the system has undergone a post deployment calibration and system check, planned for early 2021.

In addition to the website, there is a new You-tube channel, where all the videos for IAGOS can be seen. Social media tags for Twitter, You-Tube and Linked-in are IAGOS_RI.
Relative humidity over ice and in particular ice-supersaturated air masses with relative humidity over ice > 100% are of major importance for the occurrence and life cycle of high ice clouds, or cirrus clouds, respectively, which have a large but still not fully understood impact on Earth’s climate. Additionally, regions of ice-supersaturated air masses are those regions where long-lived contrails and contrail-cirrus are generated by cruising aircraft, causing the major non-CO₂ climate impact of civil aviation. In this context, long-term observations of water vapour properties are key to studying potential changes of its abundance in the global upper troposphere and lowermost stratosphere, and the resulting effects on atmospheric radiation as well as on cirrus cloud occurrence and life cycle.

IAGOS aircraft have observed relative humidity over ice (RH_{ice}) and water vapour mixing ratio (H₂O) since 1994. In a recently published study (Petzold et al., 2020), IAGOS researchers analysed the distribution properties of relative humidity of ice and of ice-supersaturated regions in the extratropical upper troposphere and lowermost stratosphere regions for a latitudinal band reaching from Eastern North America across the North Atlantic to Europe, and for the period from 1995 to 2010.

The investigation showed that there is a strong seasonal variation of the occurrence of ice-supersaturated air masses in the study regions which is closely linked to the occurrence of ice clouds. Notably, there was no trend found in the occurrence frequency of ice-supersaturated air masses for any of the study regions over the analysed 15 years. The high quality and very good resolution of MOZAIC and later IAGOS observations of relative humidity over ice will certainly help to further improve the representation of ice-supersaturation in numerical weather and climate forecasting models.

IAGOS cloud measurements reveal the global scale of aircraft engine exposure to ice crystals

Aircraft experience highly variable conditions at high altitude that involve ice crystal ingestion by jet engines, which is a potential safety consideration for aircraft operations. Work published as part of the special issue ‘Weather and Aviation Safety’ in the journal Atmosphere reveals that commercial aircraft routinely experience high altitude ice clouds, but importantly, these are highly variable depending on the season and region of the world the aircraft are flying in. The Backscatter Cloud Probe (BCP), which is fitted on all IAGOS aircraft, detects the density of ice particles using scattered light. The authors analysed these data on the aircraft flight paths, finding changes in ice clouds that could be related to seasonal changes driven by large scale weather patterns such as the sub polar jet stream, which drives storm systems across the North Atlantic, and the Inter-Tropical Convergence Zone that influences the position of severe thunderstorm development around the equator. This preliminary work will help to inform projects that aim to mitigate the impact of weather conditions on aircraft engines.

Time series of the occurrence of ice-supersaturated air masses for latitudes 40°N to 60°N and for the regions (from top to bottom) Eastern North America (105°W to 65°W), North Atlantic (65°W to 5°W) and Europe (5°W to 30°E).

Scientific Highlights

Ice-clouds and Aviation Safety

IAGOS cloud measurements reveal the global scale of aircraft engine exposure to ice crystals

Ice-supersaturated Air-masses

IAGOS measurements reveal the global scale of ice supersaturation in the northern mid latitudes
During the summer of 2016, there were two China Airlines aircraft equipped with IAGOS instruments that made daily flights to and from Taipei. They enabled us to study the changes to atmospheric composition throughout the 2016 typhoon season when seven tropical storms or typhoons affected the island of Taiwan. The seven storms (Typhoon Nepartak on 6–7 July, Severe Tropical Storm Nida on 30–31 July, Typhoon Meranti on 11–13 September, Typhoon Malakas on 16 September, Typhoon Megi on 25–26 September, Typhoon Sarika on 15–16 October and Typhoon Haima on 19–20 October) came close enough to Taiwan for vertical profiles of ozone, carbon monoxide and relative humidity to be obtained at less than 1000 km from the centre of the storms by IAGOS aircraft taking off or landing at Taipei.

We focused on the landing and takeoff profiles during the three typhoons, Nepartak, Nida and Megi, and used meteorological analyses (ECMWF Era-5) to elucidate the dynamical origin of the anomalies in the vertical distribution of carbon monoxide, ozone and water vapour. Ahead of the typhoons, the measurements showed increased ozone, decreased carbon monoxide and drier air which were related to the compensating downward flow of air from the stratosphere.

The typhoons also had a cleansing effect on the atmosphere. After the passage of the typhoon, cleaner, unpolluted marine boundary layer air, low in ozone and carbon monoxide and more humid, was lifted by the typhoons and transported up the atmospheric column. The results show how tropical cyclones participate in stratosphere troposphere transport and suggest that this transport could be a regular feature of typhoons, and therefore be important in the budget of ozone in the upper troposphere.

**Scientific Highlights**

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**Typhoons**

**Typhoons pollute and then clean the atmosphere**

Flight from Taipei to Fukuoka within the outer cloud band of typhoon Megi seen by the satellite Himawari on 26 September 2016.
Because of its high spatial and temporal variability and limited observations, quantifying net tropospheric ozone changes across the Northern Hemisphere on time scales of two decades is not an easy task and had not been possible before. Gaudel et al., 2020 have shown, using two decades of observations from IAGOS, that tropospheric ozone has increased above 11 regions of the Northern Hemisphere since the mid-1990s, consistent with satellite data. The net result of shifting anthropogenic ozone precursor emissions has led to an increase of ozone and its radiative forcing above all 11 study regions of the Northern Hemisphere, despite the reduction in nitrogen oxides emission in midlatitudes.

IAGOS reveals increases of tropospheric ozone at multiple locations across the Northern Hemisphere.
The influence of lightning emissions on the composition of the troposphere is subject to some debate and great uncertainty. In this project, a new digital tool (SOFT-IO-Li) is under development which aims to generate new value-added products by merging airborne IAGOS observations with lightning observations from terrestrial sensing networks and US GLM space detectors (Global Lightning Mapper) and European MTG-LI (Meteosat Third Generation Lightning Imager).

The SOFT-IO-Li project funded by CNES (Centre National d’Etudes Spatiales), aims to implement the systematic use of lightning data from GLM space detectors available from the AERIS data centre and from the NLDN terrestrial network, pending the first observations from the European LI space detector, and correlate these with the airborne nitrogen oxide (NO+NO$_2$=NOx) observations from IAGOS. The project aims to provide added-value products for users of IAGOS data. The tool will use recent ERA5 data from ECMWF. SOFT-IO-Li is a digital tool coupling the Lagrangian model FLEXPART, which provides the trajectory of the NOx measurements, together with IAGOS measurements and GLM and NLDN observations. The tool will provide a database of lightning characteristics including chemical (excess NOx, ozone, CO, relative humidity; estimated life of the air mass), electrical (total number of flash, strokes, peak currents, histogram of distributions) and cloud (brightness temperature, horizontal extension, geographic coordinates, weight of each cell in the contribution to the observed air mass) information.
Sand and dust from arid regions is increasingly a problem for gas turbine engines on both military and civil aircraft. The cause damage in a number of different ways which may accelerate the loss of engine efficiency, resulting in increased fuel burn and a substantial reduction in component life, requiring early and expensive removal of engines for repair. The primary damage mechanisms which affect engine performance, are erosion in high speed compressors, and the buildup of deposits on turbine aerofoils. The financial impact of this damage on companies like Rolls-Royce runs into multiple billions of pounds. Rolls-Royce's business model depends on understanding the rate of engine performance and the deterioration of components so that the company can set the service charge rate correctly, and ultimately find design solutions to mitigate the damage. Rolls-Royce makes the bulk of its income from service – or power-by-the-hour – contracts with airlines. Charging airlines that regularly operate in sandy and dusty environments an appropriate hourly rate is vital to the company’s viability. The University of Manchester is working with Rolls-Royce to better understand the composition and physical characteristics of atmospheric sand and dust along frequently used flight routes. It is important to understand the composition and nature of dust in the atmosphere and also the chemical and mineral composition, physical characteristics and the changes in particle size distribution as sand and dust travels through a gas turbine engine. Contributing to this, the backscatter cloud probe on IAGOS aircraft is being used to analyse the size distribution of the dust particles to which civil aircraft are being exposed on flights operating in and out of the Middle East.

The climate impact of global aviation has a large contribution from the ice crystals which form on the particles emitted from the aircraft engines. These ice crystals become visible as condensation trails or contrails, respectively which under certain conditions transform into large-scale ice clouds. The goal of the EU H2020 Research and Innovation Action project ACACIA (Advancing the Science for Aviation and Climate) is to improve the scientific understanding of those impacts of aviation on climate that have the largest uncertainty, in particular, the indirect effect of aviation soot and aerosol on clouds and to provide the knowledge basis and strategic guidance for future implementation of mitigation options, giving robust recommendations for no-regret strategies for achieving reduced climate impact of aviation. ACACIA brings together research across scales (from plume scale to global scale), from the laboratory experiments to global models, and it proceeds from fundamental physics and chemistry to the provision of recommendations for policy, regulatory bodies, and other stakeholders in the aviation business. Additionally, ACACIA will cooperate with international partners, both research institutions and organisations. IAGOS contributes to ACACIA high-resolution reference datasets of water vapour, clouds, aerosol and chemical tracers from both IAGOS-CORE and IAGOS-CARIBIC and leads the work on the design of concepts for future international measurement campaigns aimed at better climate metric assessments and more reliable quantification of impacts.

The European ATMO-ACCESS project is funded for 4 years (April 2021-March 2025). The ATMOS-ACCESS project is a joint venture with the research infrastructures IAGOS, ICOS and ACTRIS. The aim is to put in place an economic structure which will provide virtual and physical access to the observation and experimental platforms for atmospheric research.

The French project OBS4CLIM is funded for 8 years (2021-2028). OBS4CLIM is a project funded in France to reinforce the synergies amongst the three research infrastructures, ACTRIS, ICOS and IAGOS. OBS4CLIM will help fund the development of new services, common to the three infrastructures, such as a denser measurement network, longer time-series, links with satellite measurements, or increasing the global coverage of the network.
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)
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 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) 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 J.H. Butler, NOAA, USA (Chair); J. Haywood, UKMO, U.K.; G. Pappalardo, CNR, Italy; V.-H. Peuch, ECMWF and David Crisp (NASA JPL). AIRBUS is represented by Rainer Von Wrede and Jonathan Preist.

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 2018, these were: Lufthansa, Air France, China Airlines, Cathay Pacific, Hawaiian Airlines, and Iberia (see pictures below for details of the aircraft involved).

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.

16 January 2020
(4 EB members, P, VP, ES)
- Annual Report 2019
- Activity plan 2021
- Preparation Annual Meeting in Toulouse
- Status of Operations
- Strategy Planning

23 April 2020
4 EB members, P, ES)
- Status of operations due to COVID-19
- Project EQUIPEX
- Update on branding
- ENVRI MoU

8 September 2020
(4 EB members, P, VP, ES)
- Preparation of GA on 20th November
  - Discussion on IAGOS operations
  - Implementation Plan 2021
  - Activity Plan 2021
  - Aircraft installations 2020-2022
- Preparation of the AB meeting
- Future composition of the AB
- Media Training
- Report of ES

19 October 2020
4 EB members, VP, ES)
- Review of documents for 14th GA
- Preparation of 7th Advisory Board meeting
- Update on Green Deal discussions

General Assembly

11 March 2020
- Approval of the Activity Plan for 2020 and implementation plan
- Decision on threshold for voting rights
- Approval of the Budget for 2020
- Approval of the Annual Report for 2019

19 November 2020
- Report on Operations and Planning
- Approval of the Budget for 2020
- Approval of the Activity Plan for 2020, pending availability of Members’ resources (to be confirmed in spring 2020)
- Report on activities on EU projects
- Annual Meeting 2020 Toulouse

Advisory Board

18 November 2020
- Welcome to new Advisory Board member Jonathan Preist from Airbus
- Review of actions in response to recommendations made at last meeting
- Managing change – aircraft type, personnel changes, instrument and technical
- Partnerships
- Communications –visibility and PR
Technical Planning Group

Frankfurt, 03.03.2020 – TPG Meeting
- Planning and coordination of IAGOS-CORE aircraft installations
- Package 1: Operation status, Part 145 maintenance and replacements planning
  - Package 1 improvements planned
- Package 2: Certification and plans for equipment on aircraft
- CARIBIC - Report from Harald Boenish
- Budget
- Preparation of TPG Strategy Meeting of March 11-12 before GA (cancelled)

13.05.2020 – TPG Report
- Aircraft data measurements are limited to D-AIKO (P1 + P2d)
- Caribic aircraft is retired since 18.03.2020
- First spare Package 1 availability is delayed from May 2020 to July 2020
- Additional spare Package 1 availability is delayed from June 2020 to September 2020

13.11.2020 – TPG Report
- Aircraft data measurements are limited to D-AIGT (P1 + P2b) and D-AIKO (P1 + P2d)
- First spare Package 1 availability is expected from October 2020
- Additional spare Package 1 is expected from October 2020
- IAGOS installation on Lufthansa D-AIKB planned for Autumn 2020 is cancelled

Technical Operations Group

Teleconferences
(03.2020, 06.2020, 11.2020)
The teleconferences cover the same five topics with additional points discussed when necessary.

1. Status of IAGOS-CORE operations P1, ICH, BCP, P2b, P2d on A/C core
2. Status of CARIBIC operation
3. Status of Maintenance Centre Operations
4. Status of instrument certifications
5. Status of new aircraft installations

- integration study of CARIBIC on A350
- Part 145 MO LGM/SNT for P1
- FAA agreement for GOMOLZIG Aircraft Services GmbH (GAS)
- stowage plate retrofit for the BCP hermetic version
- P2b and P2d (Major change) EASA certification
- P2c qualification.
- P2e design status.
- discussions with CAL for new A330
- discussions with Finnair for new A330
- discussions with DLH for new A330
- discussions with IBERIA for new A330

Communication and Outreach

- IBISBA Kick-off meeting, Paris
- Virtual Booth at the Farnborough International Airshow
- Presentations at International Conferences (see Presentations)
  - European Aerosol Conference (Virtual)
  - American Geophysical Union (Virtual, 23-27 September 2020)
Activities 2020

The current IAGOS-CARIBIC payload of 19 instruments is provided by 12 institutes, 11 from Europe (Germany, UK, Ireland, Sweden, Netherlands) and 1 (NOAA) from the US. Five institutions are members of the AISBL: Karlsruhe Institute of Technology (KIT), Max-Planck society (MPG), German Aerospace Center (DLR), Leibniz Institute for Tropospheric Research (TROPOS), and Forschungszentrum Jülich (FZJ).

KIT coordinates IAGOS-CARIBIC and operates the CARIBIC laboratory since April 2015. KIT is also responsible for the operation of four in-situ instruments for the analysis of H₂O, cloud water/ice, ISOWAT for H₂O isotopic composition, and a PTR mass spectrometer for selected volatile organic compounds (VOCs) such as acetone, acetonitrile, and methanol.

MPI-C maintains the operation of the whole air sampling systems, a CO instrument, and a single particle soot photometer. In the laboratory, three GC systems for greenhouse gases, non-methane-hydrocarbons and further N- and S-containing species are used for measuring the altogether 118 air samples collected during one flight sequence. In 2017, a bio-aerosol analyser (Wideband Integrated Bioaerosol Sensor, WIBS-NEO)

After the operation of the Airbus A-340 was stopped in March 2020, a detailed characterization of the aerosol mass spectrometer (CARIBIC-AMS) regarding pressure-dependent inlet transmission and ionization efficiency was conducted. Additionally, the performance of the instrument was improved by refining the electronic control of the chopper wheel that is needed for size resolved measurements.

IAGOS-CARIBIC

One AIRBUS A340-600 by Lufthansa carries provisions for operating the IAGOS-CARIBIC Flying Laboratory, a modified cargo container with state-of-the art instrumentation for in-situ and remote sensing measurements, and for the collection of whole air and aerosol samples. The latter are analysed in different European laboratories for a detailed view of the atmospheric composition at flight altitude. The aircraft carries a special inlet probe, which is connected to the instruments inside the laboratory. Operation of the CARIBIC laboratory is discontinuous with 10-12 sequences per year, each for 4 consecutive flights.

DLR is responsible for the operation of an instrument for measurements of nitrogen oxides (NO and NO₂) and total odd nitrogen (NOy) aboard the CARIBIC container. The measurement system worked successfully during the flights in 2020. The data was evaluated and made available for the database. Since the Airbus A340-600 was taken out of service, the measurement system is being rebuilt. Design, size and weight is being modified for future use on an Airbus A350.

TROPOS is responsible for operation of instruments for the operation of instruments measuring the particle size distribution and the chemical particle composition onboard IAGOS-CARIBIC. As a consequence of the coronavirus pandemic, Lufthansa took the IAGOS-CARIBIC aircraft out of service and thus no measurement flight were conducted. Instead the aircraft-changeover to an Airbus A350 as new IAGOS-CARIBIC aircraft was supported by TROPOS.

FZJ is responsible for the IAGOS-core package 2 instrument slot in the CARIBIC laboratory, integrated in 2017. Currently the aerosol package is installed which contains two CPCs and an OPSS.

MPI-BGC is responsible for the picarro CRDS carbon dioxide and methane measurement system. Since first data were provided in July 2018, and after a software modification in early 2019, the instrument has been running fully reliably and has provided high quality data for all flights up March 2020, when the aircraft was grounded due to the COVID-19 pandemic.
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). 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 2a and 2b are intermittently flown on Lufthansa D-AIGT. The Installation of Package 2d was completed in September 2018 on D-AIGT. See page 7 for operations in 2020.

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 had been successfully completed in 2012 for Taiwan (China Airlines) and in 2013 for Hong Kong (Cathay Pacific). 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 set of P2 instruments is still under certification. One aircraft (Lufthansa D-AIGT) is certified to carry P2a or P2b. With the EASA certification of the P2d instrument obtained in December 2016, it is planned to install the new instrument for measurements of greenhouse gases (P2d) successively on IAGOS-CORE aircraft.

Activities of Members

Activities 2020

One Real Time Transmission Unit (RTTU) is installed on the aircraft D-AIGT operated by Lufthansa. It was installed in 2017 and for few months, transmitted data via SATCOM to the EUMETNET E-ADAS facility which was established to receive and forward AMDAR data to the WMO Information System (WIS). The telecom provider was changed by Lufthansa in 2018. Some modifications to the RTTU are required before it can transmit data via the new operator. Studies have been carried out to explore the best approach to continue the transmission of data in real time with the RTTU. A certification of the new system is underway.

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** 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. FZK 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.
In the reporting period 2020, FZJ focused on the operation of the existing infrastructure under the global flight restrictions caused by the COVID-19 pandemic. From German resources, the installation of IAGOS equipment on the 3rd aircraft of Deutsche Lufthansa was prepared and the certification of the various Package 2 types was promoted. In addition 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, with its first target being the automated analysis of NOx data.

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 establishes fully automated and scalable data management and QA/QC workflows for the IAGOS instrumentation under the responsibility of FZJ. The workflows are designed for broad application in IAGOS after a successful testing phase.

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 and aerosols. FZJ is also engaged in the Copernicus Atmosphere Monitoring Service.

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).

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In the reporting period 2020, as planned, CNRS financed two units of Package 1 and several maintenance kits to adapt the system to the new maintenance process in France which is now performed by LGM and Sabena. 2020 has been an unexpected year on many aspects and the different activities have been quite difficult or very long to handle. Most of the fleet was grounded in March 2020 due to COVID-19.

A major part of the activities concerned the finalization of the maintenance process and the operation of the equipment (including the acquisition system and transmissions) aboard the two Lufthansa IAGOS-CORE aircraft. Despite the 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. This service is required by ECMWF under the CAMS-84 contract, which focuses on the evaluation of regional and global models with ozone, CO, and water vapour data. Even with a lower amount of recorded data, CNRS continued to produce periodical reports for CAMS-84. CNRS is engaged in CAMS-84 phase 2 (as sub-contractor of KNMI) until June 2021 (a duration of 33 months from October 2018).

Development of the database in 2020 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 2020, major improvements have been followed up thanks to additional resources through the ENVRI-FAIR project (started in January 2019; coordinated by FZJ, with the Atmospheric domain being co-lead by CNRS as IAGOS Members). In 2020, the iagos.org web site was moved to Toulouse, thus facilitating its management by Damien Boulanger (responsible for the IAGOS Data Center) and Hannah Clark (Executive Secretary).

In 2020, CNRS has been deeply involved in the writing process of 2 European projects (ATMO-ACCESS, funded, to start in April 2021; RI-URBANs, submitted in January 2021), and 1 French project (OBS4CLIM, funded, to start by summer 2021).
Météo-France is responsible for the RTTU, i.e. the real realtime data transmission of the IAGOS-CORE data to the WMO Information System (WIS) for operational users, particularly the Copernicus Atmosphere Monitoring Service. After the SATCOM system was changed by Lufthansa in 2018 the RTTU stopped transmitting real time data. In 2020, Météo-France continued discussions with Lufthansa Technik and the subcontractor ATMOSPHERE, as well as Lufthansa and its new satellite telecommunications provider, in order to define best way to proceed with the operation of the RTTU already installed, and to ensure the delivery of real time data from additional aircraft in the future. Several options have been explored but due to the coronavirus pandemic, no further progress has been made in 2020 regarding updating the real-time capacity.

The Institute of Biogeochemistry (MPI-BCG) of MPG is responsible for operation of an instrument 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 in 2020, starting on February 20, but interrupted in mid December when the aircraft was grounded and P2d was deactivated due to the COVID-19 pandemic. High quality data was retrieved from about 50% of the flights, while for the rest of the flights an intermittent error developed that is being addressed using the P2d SN03 instrument in the lab. Data transmission via GSM was not functional, but direct download through Lufthansa personnel was possible via USB, and was performed several times. The exchange of calibration gas cylinders was planned for Dec 2020, but this was postponed until the reactivation of P2d, currently scheduled for early 2021. During the deployment period in 2020, high quality data have been acquired from a total of 94 flights. In-flight calibration results confirmed excellent traceability of CO2, CH4 and CO data to WMO calibration scales. Submission of the P2d data to the IAGOS database will begin after the instrument has been back to the laboratory for maintenance and calibration, currently planned for the first half of 2021.

The assembly of three further P2d (SN02 – SN04) has been completed, and the last two (SN05 and SN06) are expected to be assembled within 2021 (all parts in stock). As SN02-SN06 differ slightly from SN01, the completion of the major change of the STC is required before those packages can be deployed onboard CAL and HAL aircraft. This major change is expected to be completed in 2021.

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 have worked 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 until the newer BCP (version BCP-H). Certification for the newer BCP-H versions has been completed and we will start gradual replacement as the older instruments undergo refurbishment.

The droplet gun/laser mapping calibration facility at UMAN was rebuilt and new personnel (supported by NCAS) have been trained to speed up calibration and data delivery. Links with NCAS research scientists to make use of the droplet/ice generation facility. Further upgrades to the system have been made since and the system is provided for student training (MSc and PhD projects). Ongoing work includes upgrades to investigate ice particle calibration response to provide improved higher level cirrus-cloud data products (i.e. effective diameter).

Metadata file information for the BCP has been improved and software tools are available to improve routine data analysis. In collaboration with manufacturers DMT, new data from test flights of the BCP and the updated BCP/D for improved size resolution and particle phase discrimination have been investigated. The BCP/D has now been permanently installed on the UK FAAM BAe146 research aircraft for on-going data collection and comparison with cloud and dust spectrometers operated by FAAM and UK groups. BCP and BCP-D can be swapped/interchanged using this platform for various improvement assessments due to a common mounting template.

The BCP-D completed initial operation in 2018 as part of the UK PICASSO and MOCCA projects. It will also be deployed as part of recently funded NERC cloud-climate sensitivity projects including; M-Phase (October 2020 in Canada) and DC-MEX (July 2021, USA). The data collected will continue to be used as a reference database for BCP data interpretation and improvement of retrieval algorithms by comparison with state-of-the-art research cloud instruments.

Activities of Members
There is agreement with FAAM-NCAS to provide support for the BCP/D routine data as part of NCAS support for IAGOS 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.

In collaboration with FZJ the power of integrated IAGOS RHice and Nice (BCP) pdf data products was demonstrated in a Royal Society Faraday Discussions publication (Petzold et al. 2017). A grant application to assess impacts of IAGOS BCP data products among commercial end users began in 2019. Visits and interviews includes Satavia UK who are working with Rolls Royce. Satavia are using IAGOS data to enable aircraft equipment manufacturers and operators to minimise unscheduled aircraft maintenance caused by the environmental impacts and we are providing expertise on BCP data analysis.

A new NCAS instrument scientist, Dr. N. Marsden, was hired in January 2021. He will be responsible for the Manchester cloud instrumentation on the FAAM aircraft and will also assist Dr. Lloyd with laboratory calibration of the IAGOS BCP and the BCP on the FAAM aircraft. Dr. Marsden confirmed that he is keen to improve BCP laboratory calibration techniques and, having an extensive track record in designing aerosol instruments, will look to develop next generation versions of BCP and is looking to obtain seed-corn funding from NCAS for this.

All BCP data from 2019 to 2021 has now been quality controlled and delivered to the IAGOS database. These data will form the backdrop for a number of projects examining the impact of COVID-19 on air traffic.

A scientific article on global in situ cirrus measurements using IAGOS aircraft was published in January 2021 (see highlights section). This work was in collaboration with the IAGOS team at Juelich and the US instrument team at DMT [Petzold, Kramer & Baumgardner]. This work demonstrated how stratospheric and tropospheric in situ data can be used to calculate the cloud fractions routinely experienced by commercial aircraft. However, further work is needed for a direct comparison with previous studies that were limited to mainly cloud fraction calculations for tropospheric data only.

IAGOS data remains a component of Physics Masters degree projects at Manchester and Dr. Lloyd has supervised two masters students in 2020-21, assisted by Prof. Gallagher. Due to the pandemic funding for the proposed dust programme with Rolls Royce (PI Dr. M. Jones and Rolls Royce supervisor R. Clarkson) has been delayed until Autumn 2021. The BCP dust profile data for this project has been analysed for the appropriate regions of interest and provided to the team. These data sets also formed part of projects for two MPhys students.
IAGOS Maintenance Centre

The company enviscope GmbH is in charge of the maintenance and aeronautical management of the instruments operated on board civil aircraft. The calibration of the instruments 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 has been 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 database;
(ii) improvements of the database to handle logistics and documentation;
(iii) logistics like instrument storage and shipment (see Table 1), and handling of instrument exchange intervals (under coronavirus and pre-Brexit conditions);
(iv) instrument maintenance, repair, overhaul, servicing, testing and parts production;
(v) support for data download at aircraft and P1 data transmission;
(vi) transfer of the IAGOS website to CNRS;
(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 and shipment of retrofit kit (stowage bracket) to Hawaiian Airlines;
(x) assisting Gomolzig in applying for FAA approval by translation of documents;
(xi) audit by LBA without findings;
(xii) audits and trainings held at the institutes in order to make enviscope an EASA and FAA repair station for IAGOS components;
(xiii) enviscope personnel became certifying staff of Gomolzig and can issue EASA Form1 (including dual release for FAA) for all IAGOS components (incl. Package1 unit and pump box). In addition, enviscope organizes the shipments of P2c between FZJ and KIT for measurements on IAGOS-CARIBIC. The IMC stayed fully operational and was unaffected by COVID-19 restrictions due to the adaption of the working environment.

<table>
<thead>
<tr>
<th>Item</th>
<th>Member</th>
<th>Airline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>FZJ</td>
<td>CNRS</td>
</tr>
<tr>
<td>Package 1</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Package 2ab</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>O₂ Cylinders</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Pump Box</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>BCP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ICH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Package 2d AIR</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Auxiliary parts</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Shipments of instruments and auxiliary parts for IAGOS-CORE operation in 2020
Financial Information

Balance 2020

<table>
<thead>
<tr>
<th>Income</th>
<th>Membership Fees</th>
<th>130,000€</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Income</td>
<td>130,000€</td>
<td></td>
</tr>
<tr>
<td>Expenditure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personnel incl. overheads</td>
<td>56,424€</td>
<td></td>
</tr>
<tr>
<td>Services and other expenses</td>
<td>13,183€</td>
<td></td>
</tr>
<tr>
<td>Total Expenditure</td>
<td>69,607€</td>
<td></td>
</tr>
<tr>
<td>Amount carried forward from 2019</td>
<td>79,523€</td>
<td></td>
</tr>
<tr>
<td>Total Balance December 2020</td>
<td>139,916€</td>
<td></td>
</tr>
</tbody>
</table>

Resources dedicated to IAGOS by the Members

In 2020, the Members contributed in total approximately 7.3 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 Statutes, is listed in Table 1.

Table 2: Contributions by the Members to construction and operation of the infrastructure from institutional resources and national funding

<table>
<thead>
<tr>
<th>Member</th>
<th>Operation &amp; hardware (k€)</th>
<th>Personnel (k€)</th>
<th>Total (k€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FZJ</td>
<td>719</td>
<td>1107</td>
<td>1826</td>
</tr>
<tr>
<td>CNRS</td>
<td>651</td>
<td>897</td>
<td>1548</td>
</tr>
<tr>
<td>MPG</td>
<td>282</td>
<td>550</td>
<td>831</td>
</tr>
<tr>
<td>MF</td>
<td>39</td>
<td>15</td>
<td>54</td>
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<td>UMAN</td>
<td>50</td>
<td>134</td>
<td>184</td>
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<tr>
<td>DLR</td>
<td>108</td>
<td>69</td>
<td>176</td>
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<tr>
<td>TROPOS</td>
<td>124</td>
<td>188</td>
<td>311</td>
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<tr>
<td>KIT</td>
<td>1667</td>
<td>676</td>
<td>2343</td>
</tr>
<tr>
<td>TOTAL</td>
<td>3638</td>
<td>3636</td>
<td>7274</td>
</tr>
</tbody>
</table>

¹NOTES: 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 266 k€ were deployed in 2020 due to co-funding by the European Union for coordination with other European RIs (ENVRI-FAIR), and contributions to the Copernicus Programme (CAMS-84).
The Members of IAGOS-AISBL acknowledge the funding received from Germany, France and the United Kingdom for the construction phase of the Research Infrastructure and co-funding by the European Commission for development of the infrastructure, coordination with other RIs and for contributions to the Copernicus Atmosphere Monitoring Service. The IAGOS data center is sponsored by 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.


Presentations at International Conferences

1. Bennouna Y, Effects of the COVID-19 Lockdown on Air Quality as seen by IAGOS In-situ Data, American Geophysical Union Fall meeting, online, 1-17 December 2020.


3. Tsivlidou, M., Distribution and Seasonal Variability of Ozone and Carbon Monoxide over the Tropics with 20 Years of Measurements, American Geophysical Union Fall meeting, online, 1-17 December 2020.


5. Cussac, M., V. Marécal, V. Thouret, Analysis of the impact of biomass burning emissions on global ozone production in the upper troposphere with MOCAGE CTM and IAGOS airborne data. 22nd EGU General Assembly, held online 4-8 May, 2020.


