Implementation Plan

2025

IAGOS

IN-SERVICE AIRCRAFT FOR A GLOBAL OBSERVING SYSTEM

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Contents

Members of IAGOS-AISBL

Acronym	Member	Country
FZJ	Forschungszentrum Jülich GmbH	Germany
CNRS	Centre National de la Recherche Scientifique	France
MPG	Max-Planck Gesellschaft zur Förderung der Wissenschaften e.V.	Germany
MF	Météo France	France
UMAN	University of Manchester	U.K.
DLR	Deutsches Zentrum für Luft- und Raumfahrt e.V.	Germany
TROPOS	Leibniz-Institut für Troposphärenforschung e.V.	Germany
KIT	Karlsruher Institut für Technologie	Germany

Note: MPG is contributing to IAGOS with two of its institutes:
MPI-C: Max-Planck Institute for Chemistry, Mainz
MPI-BGC Max-Planck Institute for Biogeochemistry, Jena

Technical Set-up

IAGOS combines the expertise of two successful European research projects, MOZAIC and CARIBIC. The complementary methodology developed in these projects is continued in IAGOS in order to fully exploit the advantages of both approaches. As detailed below, IAGOS-CORE provides continuous data of key constituents with quasi global coverage from many aircraft, whereas IAGOS-CARIBIC provides additional information for a deeper scientific understanding from one aircraft.

IAGOS-CORE

The ultimate goal of IAGOS is to equip 15 long-range aircraft of internationally operating airlines with IAGOS-CORE equipment for continuous deployment. In order to reach this goal, several conditions must be fulfilled:

1. Aeronautic Certification of the IAGOS equipment for installation aboard commercial long-range aircraft (Supplemental Type Certificate, STC) .
2. Acquisition of the necessary equipment with EASA Form 1.
3. Cooperation contracts with suitable airlines.
4. Cooperation contracts with aeronautic companies for continued airworthiness.
5. Logistics for maintenance and quality assurance.

For each aircraft modification, the following components are required (see Fig. 1):

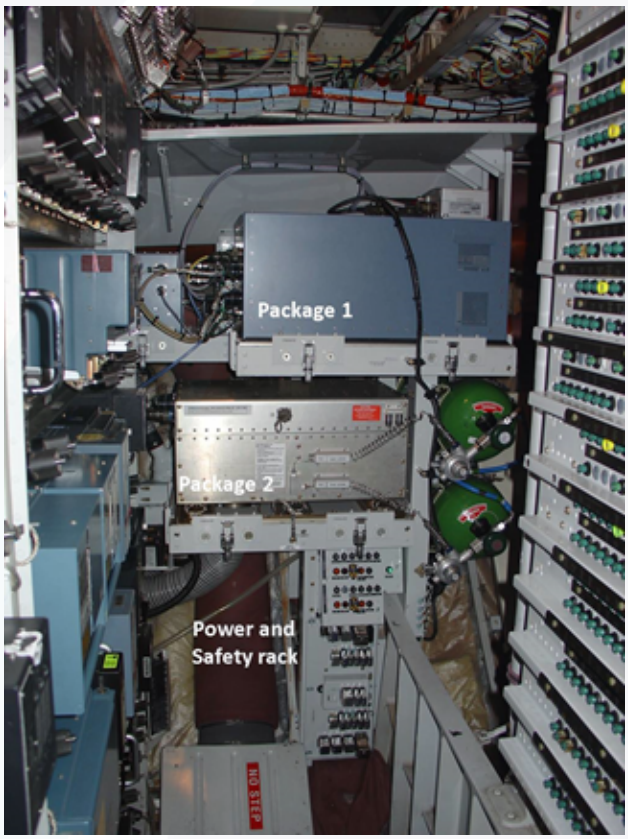

Fig. 1: IAGOS-CORE rack with instruments (P1, H_2O, BCP and P2b) installed in an Airbus A340-300 operated by Lufthansa (left) and outside view of the IAGOS-CORE Inlet Plate (top).

IAGOS-CORE

1. IAGOS-CORE modification kit, comprising the mechanical, electrical and safety provisions for installation of the instruments and a special inlet plate with the probes for connecting the different instruments to ambient air.
2. Engineering support by the airline's maintenance department and by the design organisation in charge of the IAGOS STC.
3. Scientific instruments:
   I. Package 1 (denoted P1), which contains the central data acquisition and transmission as well as the instruments for measuring ozone (O_3) and carbon monoxide (CO).
   II. Water vapour sensor (H_2O)
   III. Backscatter Cloud Probe (BCP)
   IV. Package 2 in one of four possible options:
      a. Instrument for the measurement of nitrogen oxides denoted NOx (P2b)
      b. Instrument for the measurement of aerosol number density (P2c)
      c. Instrument for the measurement of greenhouse gases, i.e. CO_2, CH_4, CO and H_2O (P2d)
      d. Instrument for the measurement of aerosol extinction and NO_2 (P2e, under certification)
   V. Unit for data transmission in real real-time via a satellite link to the WMO Information system (RTTU). Deployment has been limited to one aircraft and has been operational for a limited period of time. Real-time transmission technologies are being investigated.

Each instrument must be approved for installation on commercial aircraft by Supplemental Type Certificate and must be manufactured by a company with EASA Part 21 approval. For maintenance of the equipment, companies with EASA Part 145 approval are required.

The EASA-STC for installation of the IAGOS-CORE rack with P1, H_2O , and BCP was obtained in 2011 for A340 aircraft and in 2013 for A330 aircraft. The EASA-STC has been approved by the authorities of Taiwan, Hong Kong and USA.

The installation of P2b was certified in 2011 for Deutsche Lufthansa A340 MSN304 only. The EASA-STC for installation of P2d obtained in December 2016 for all aircraft equipped with the IAGOS-CORE system. The first P2d unit was installed and activated in September 2018 Deutsche Lufthansa D-AIKO.

A revised P2d STC was issued by EASA in December 2021, to allow minor modifications on P2d serial numbers SN003 and above.

The P2b STC was issued by EASA in January 2022 using HelOx bottles in place of oxygen bottles.

The EASA-STC for the P2e is in progress and expected soon.

All instruments have been successfully operated on different research aircraft during scientific campaigns.

IAGOS has established a Technical Planning Group (TPG) for the coordination of aircraft installations, and the development of the future fleet and future equipment, and a Technical Operations Group (TOG) for instrument operations, certification issues and maintenance of the equipment. The TOG oversees the IAGOS Maintenance Centre lead by *enviscope*.

IAGOS-CARIBIC

The Lufthansa aircraft A340-600 "Leverkusen" (D-AIHE) that carried the CARIBIC container laboratory since 2005 was retired in April 2020 due to the commercial disruption in the air traffic business caused by the COVID-19 pandemic. Based on a feasibility study in 2018, the Lufthansa Group's most fuel-efficient long-haul aircraft A350-900 named "Erfurt" (D-AIXJ) was identified as new IAGOS-CARIBIC aircraft.

The new CARIBIC configuration is depicted in Figure 2. The aircraft (Airbus A350) modification (major work packages, see list bottom left) occurred in a series of layover times between March 2021 (at Malta) and September 2024 (at Munich airport). The very minor remaining work (~3%) will be done until May 2025. The certification was implemented in two major modification steps (including a test flight in March 2023) with concluding supplement type certificates (STCs) issued by the EASA flight authorities.

The new CARIBIC air inlet system (Figure 3) will be the most complex system of its type existing worldwide, as all features (typically realized in a number of individual inlet systems) had to be combined in one multi-function version. The low-turbulence inlet for aerosol particles is able to sample aerosol particles having a diameter of at least 10 μm. The air inlet is even bird-strike certified and can resist birds having a weight of up to 2 kg.

Figure 2: CAD drawing indicating the IAGOS-CARBIC system on board the AIRBUS A350-900 "Erfurt".

Technical Set-up

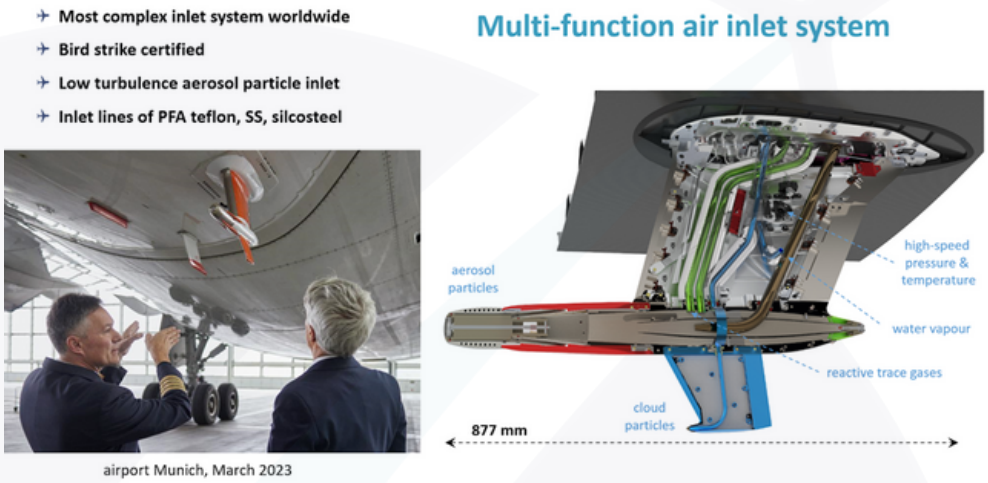

Figure 3: The new multi-function CARBIC inlet system. Right: as CAD drawing with the different inlet lines and sensors. Right: mounted on the A350-900 "Erfurt" just before the test flight in March 2023.

The frame of the new CARIBIC container was delivered in December 2023 to the KIT. After the decision of the EASA to certify the container as part of the aircraft (and not as an "active" freight as before), between January and June 2024 the KIT (workshop, laboratory, stuff) was certified as "production organization of aircraft (CARIBIC) parts". Thereafter and since July 2024 the further construction and documentation of the CARIBIC-Lab container, its tooling (of cables and the air sampling lines), the installation of laboratory infrastructure units (such as master computer, heating system control, pump unit etc.) and of the safety system (such as the laboratory control unit, smoke detectors and thermal switches) is in progress. The CARIBIC-Lab structure is ready for the A350 cargo bay smoke test scheduled for May 2025. Design documents and GTP for this certification step have been uploaded to EASA. After finalization of these works and the relevant certification documents, the CARIBIC container is certified as a major modification (with a STC, but still without instruments) by the EASA flight authorities.

In parallel, the technical modifications of the instruments required for the strongly aggravated certification are implemented, e.g. the adaptation to the new supply voltage of 270 VDC or the implementation of various safety relevant requirements (e.g. regarding thermal fuses, flammable materials or fixation of heavier components above ~2 kg). Until April 2025, the certification documents for most instruments shall be prepared by the KIT and instrument PIs. In the following three months until July 2025 the documents are further iterated and finalized together with enviscope and ACC Columbia and finally the instruments prioritized. Currently 13 instruments have the priority 1; most (or even all) shall be part of the first payload. The instrument payload will be (together with some infrastructure units) certified as a minor modification approval by the airworthiness department of ACC Columbia.

Objective is to finalize both, the container modification via the EASA, the payload certification by ACC Columbia and the conduction of all requested tests (e.g. of certain safety relevant components in the laboratory, the smoke test in the cargo bay of an A350 and the EMI test in the laboratory and the A350 "Erfurt") until December 2025, so that the first flight series on board the A350 by Lufthansa can take place in Q1 2026. As all showstopper and critical certification topics have been discussed with the EASA and disproved, the by far biggest risk of this time table is the accessibility of the EASA experts. The remaining instruments will be certified soon (8-10 months) thereafter, see the final payload in the following table.

#	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: New payload envisaged for the CARIBIC Airbus A350-900 (Lufthansa). Yellow: new instrument or new member (after the phase-out of the A340-600 in April 2020). Last line: Planned instrument, but already known as being delayed.

Planning

IAGOS-CORE

Figure 4 gives an overview of the planning for aircraft installations (black bars) and the aquisition of the necessary hardware by the Members of IAGOS AISBL.

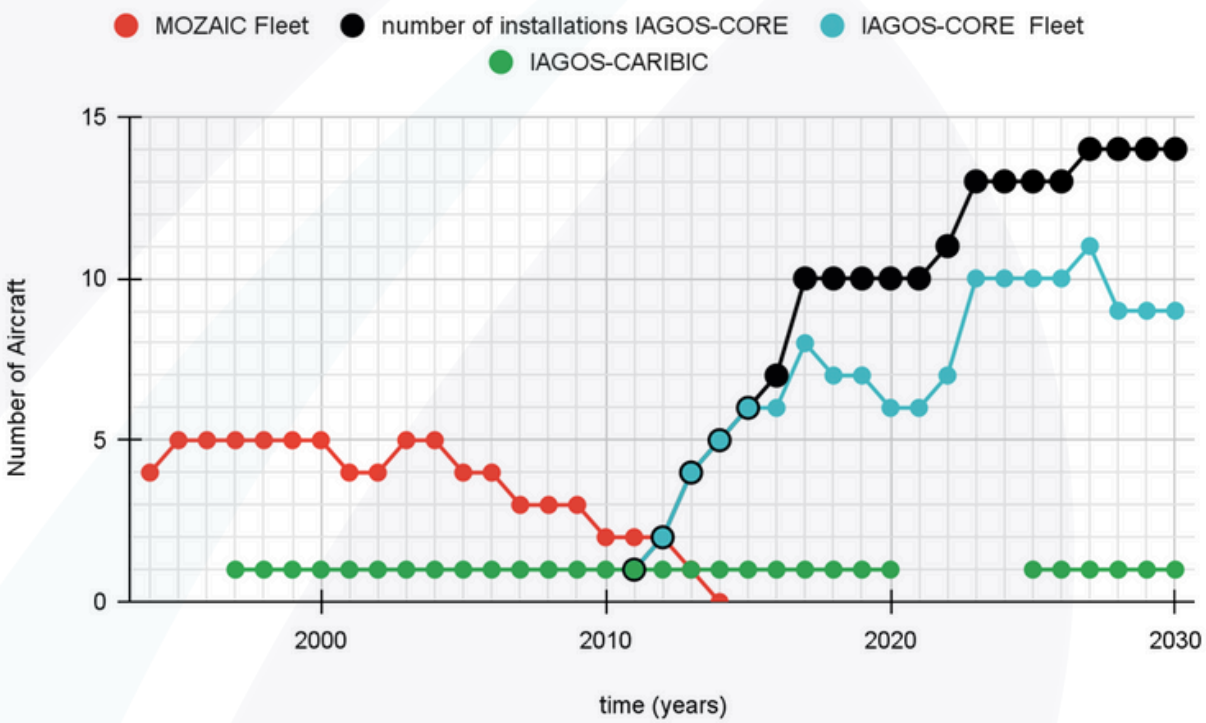

Figure 4. Evolution of the number of aircraft in operation.

The detailed planning, including the responsible Members, is listed in Table 2. The planning is annually revised and depends to some extent on the availability of financial resources, which are granted on an annual basis for the Members CNRS, MF and UMAN. Detailed planning also depends on the availability of suitable aircraft for integration. In order to avoid interference with airline operations, integration is usually done during a scheduled layover (C- or D-check) of the aircraft.

IAGOS-CORE																				
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	Total
Aircraft installations	0	1	1	3	0	1	1	3	0	0	0	0	1	2	0					14
FZJ		0,5		1		1	1	1						1						6,5
CNRS				1				2						1				1		5
NCU			1																	1
co-funding by EC		0,5		1																1,5
IAGOS Kits total	1	3	1	1	0,5	1,5	1,5	1	1	2	1,5	0,5	1	1	1	0	0	0	0	18,5
FZJ		2		1	0,5	0,5	0,5	1	1	2	1,5	0,5	0,5							10,5
CNRS		1				1	1							1	1					6
co-funding by EC	1		1																	2
Package 1 total	2	1	3	4	2	1	1	1	0	1	2	2	0	2	0	2	0	0	0	24
P1 by CNRS		1	3	4	2	1	1	1		1	2	2		2		2				22
co-funding by EC	2																			2
H2O total	0	4	0	4	9	5	10	0	0	0	0	0	0	0	0	0	0	0	0	32
H2O by FZJ		4		4	9	5	10													32
BCP Total	4	2	1	1	2	1	3	0	1	0	1	1	1	1	1	0	0	0	0	20
BCP by CNRS					1															1
BCP by FZJ	1	2			1		3													7
BCP by UMAN	3		1	1		1			1			1	1	1	1					12
Package 2 total	2	4	0	0	0	0	3	4	5	2	0	0	4	0	0	0	0	0	0	24
P2a/b by FZJ	2	2					2	2	1											9
P2c by FZJ		1					1	2												4
P2d by MPG		1							3	2										6
P2e by FZJ									1			4	4							5
RTTU	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	0	0	0	4
MeteoFrance						1														1
co-funding by EC						1														1

Table 2: Planning for aircraft installations and acquisition of hardware by the different Members involved in IAGOS-CORE, based upon current resources estimates. Numbers in black according to long-term estimation.

IAGOS-CARIBIC

The status of IAGOS-CARIBIC or of the move to the Airbus A350-900 "Erfurt" by Lufthansa, respectively, is outlined on p. 4. Besides instruments already flown in the previous CARIBIC container laboratory, altogether seven new instruments have been developed (see table on p. 6), that are

1. a mid-infrared laser spectrometer for N_2O, CH_4, CO and C_2H_6
2. a cavity ring-down laser spectrometer for N_2O_5, NO_3, O_3 and NO_2
3. a chemical mass spectrometer for SO_2, HCN and some acids
4. a further IAGOS core-slot
5. a new unit for three condensation particle samplers
6. a multi-channel sampler for cloud ice nuclei
7. an optical-feedback cavity enhanced absorption laser spectrometer (OF-CEAS) for the isotopic composition of water vapor and cloud particles.

Implementation Plan for IAGOS-CARIBIC

Last Revision:	27.03.2025															
	Year	≤2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028
Infrastructure	Member															
Container upgrade	KIT	1			1											
Container new	KIT													1		
Inlet exchange	KIT	1												1		
A/C changeover	KIT													1		
Instrumentation																
O3	KIT	1												a		
H2Otot	KIT	1												a		
H2Ogas	KIT	1												a		
OFCEAS (H2O isotopes)	KIT / Uni Grenoble	1			-1									1		
PTRMS (VOCs)	KIT	1			i									a		
UMAQS (N2O, C2H6, CO)	KIT / Uni Mainz													1		
CO	MPI-C	1												a		
HIRES (Sampler)	MPI-C	1												a		
NMHC GC-system	MPI-C	1	1											a		
SP2 (soot photometer)	MPI-C	1												a		
WIBS (bioaerosol)	MPI-C				1									a		
AMS (aerosol composition)	MPI-C / TROPOS				1									a		
PNC (aerosol number)	TROPOS	1													1	
OPSS-1 (aerosol size)	TROPOS	1													a	
HERA (INP sampler)	TROPOS														1	
NOx/NOy	DLR	1												a		
Slot for CORE P2 (no 1)	FZJ				1									a		
Slot for CORE P2 (no 2)	FZJ													1		
FUNMASS (SO2, HCN, acids,...)	FZJ													1		
PICARRO (CH4/CO2)	MPI-BGC				1									a		
CARDINO (N2O5, NO3, NO2, O3)	Cork / NOAA / KIT				1									a		
Removed instrumentation																
CH4	KIT	1			-1											
CO2	MPI-C	1			-1											
Hg	MPI-C	1			-1											
HCs	Uni UEA	1			-1											
TRAC (Sampler)	MPI-C	1														
DOAS (SO2, CH2O, ...)	Uni HD	1			i											
Aerosol sampler	Uni Lund	1														

A340-600 phase-out
no flights

Notes:	1: implemented
	-1: removed
	(1): tentative
	i: improved
	a: adapted

Table 3: Planning schedule for IAGOS-CARIBIC

Version	Published	EB approval	GA approval	Remarks
final	10.05.2025	26.03.2025	26.03.2025	

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