STANDARD OPERATION PROCEDURES FOR THE IAGOS-CORE PACKAGE 1 INSTRUMENT

Version	Author	Date
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V3	Philippe Nedelec, CNRS	28.10.2015
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Summary

Abbreviations

P1	Package 1
SOP	Standard Operation Procedures
O3	Ozone
CO	Carbon monOxide
ICH	IAGOS Capacitive Hygrometer
RH	Relative Humidity
T	Temperature
CMM	Component Maintenance Manual

Preamble

This SOP is covering:

1. P1 as a whole including O3, CO + H2O & BCP instruments, whereby SOP's of RH/T (ICH= IAGOS Capacitive Humidity) and BCP are documented separately.

2. Ozone-photometer

3. CO-photometer

SOP's for RH/T are documented into two separate reports.

Associated documents (Component Maintenance Manual from the manufacturer LGM) :

- CMM.115279.500.0 for P1

- CMM.115279.100 for Pump Box

Rationale

O3 is a key trace component of the atmosphere. Mainly present in the stratosphere (90%, a few ppmv), it is produced by the solar UV via dissociation of O2. It acts as a UV filter in the stratosphere. O3 is also present in the troposphere either transported from the stratosphere, but also photo chemically produced from the anthropogenic emission of several reactive trace gases (COV, CO, CH4 and NOx).

CO is mainly produced by incomplete combustion of hydrocarbons from human activities and biomass burning. Its relatively long lifetime in the troposphere (few months) makes from CO an excellent tracer of emissions. Through its slow oxidation process, it is also a precursor of O3.

This SOP document presents an overview of the P1 instrument technical aspects for O3 and CO measurements in the scope of the IAGOS-CORE program. It also aims to describe, for a traceability purpose, the maintenance procedures and the pre and post calibration process.

Description of P1

Principle

The IAGOS P1 is derived from the previous 2 Mozaic instruments, operated on Airbus aircraft since 1994 for O3 and 2001 for CO. The 2 instruments are included into one box. O3 measurements are performed by classic UV absorption at 254 nm as described in *Thouret et al.,* 1998. CO measurements are improved IR correlation, as described in *Nedelec et al.,* 2003. P1 is associated in the system with a Pump Box which contains 2 pressurisation pumps for driving air from to pitot tube to the atmospheric pressure.

P1 also includes the acquisition/control of H2O and BCP instruments, acquisition of the aircraft parameters as position and meteorological parameters and communication with optional Package 2 instrument via Ethernet.

The IAGOS system is designed for deployment aboard Airbus A340 and A330 aircraft as part of the IAGOS project The IAGOS installation provides a mounting rack with electrical and pneumatic provisions for installation and operation, as well as the central data acquisition system which collects the aircraft position and other aircraft parameters that are relevant for geo-referencing of the measurements. These data are transferred via Ethernet connection to Package 2 for its proper needs. The data measured by P1 (and H2O, BCP and optionally by Package2) are transmitted to CNRS reception centre via GSM (GPRS) when the aircraft is on ground.

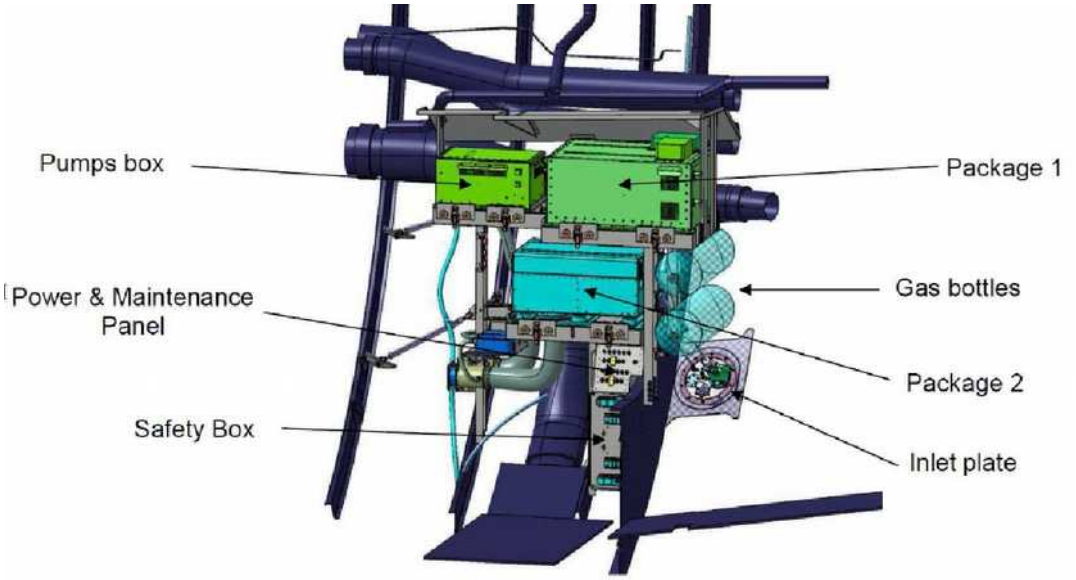

Figure 1: IAGOS system installation aboard Airbus 330 aircraft

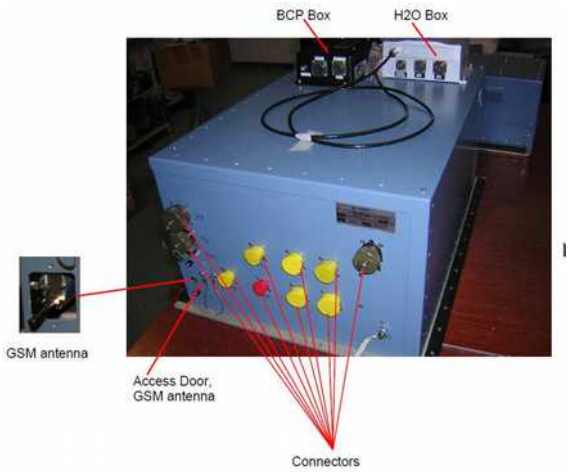

Figure 2: Package 1 external view

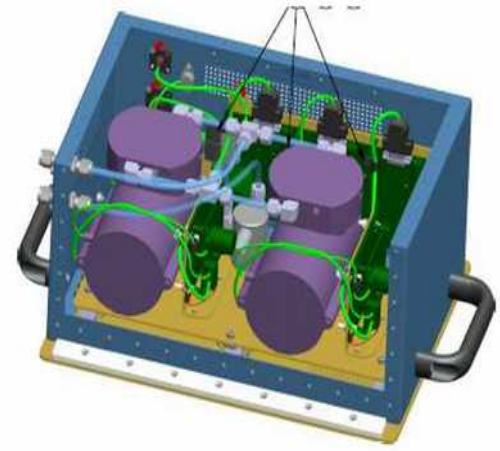

Figure 3: Pump Box

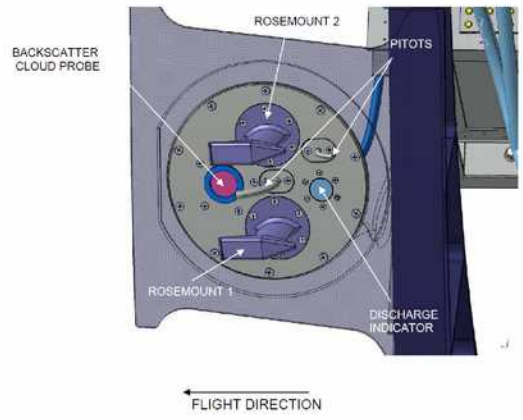

Figure 4: IAGOS Inlet plate

Air from inlet plate pitot tube (Figure 4) is driven by the Pump Box to port "Ext Pump Air Out". Air is at cabin pressure in the manifold and air excess is monitored to check the pumps flow (25 l/min on ground, 5 l/min in altitude). The flow needed for P1 is 4 l/min, driven by the internal pump and divided into almost equal parts to O3 and CO measurement devices.

All inlet lines (about 2m) internally consist of Teflon tubing in order to avoid any wall losses of ozone. The pitot tube is Teflon coated inside. As the flow is minimum 4l /min in altitude, the residence time of the air in the inlet line is less than 1 second and O3 loss on walls are expected to be less than 1%. This is checked in laboratory after regular exchange of the equipments from aircraft.

Description of the instrument

IAGOS P1 has been developed by CNRS on the Mozaic experience for routinely measure O3 and CO aboard commercial aircraft. The design and the realisation have been done sub-contracting companies in Toulouse, first Lacroix Electronique, and then LGM since 2010. The instruments are qualified to aeronautic certification procedure DO-160.

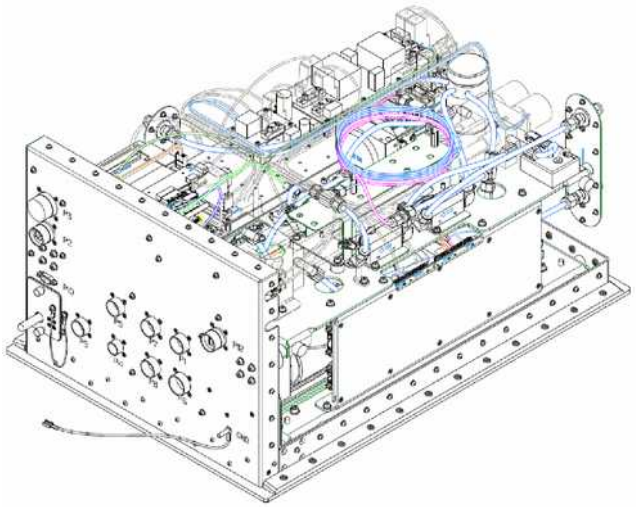

Figure 5: IAGOS Package1 internal views.

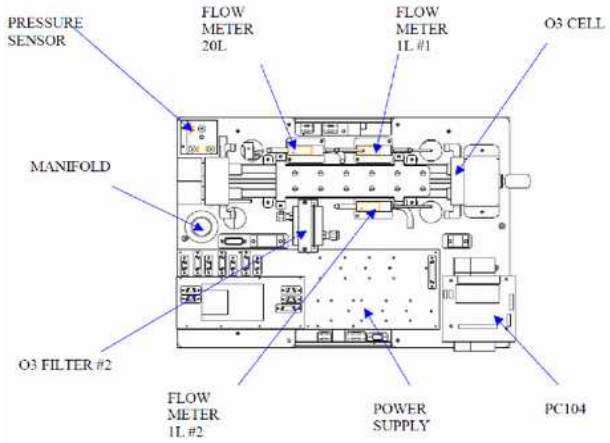

Figure 6: Upper shelf

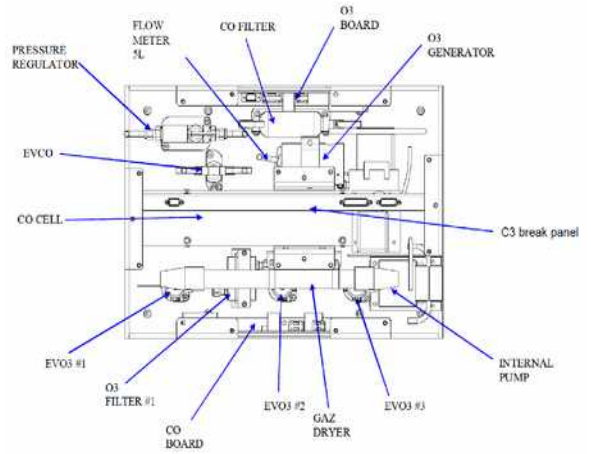

Figure 7: Lower shelf

Main Element	Function and description
Upper shelf	
O3 device	O3 absorption cells, UV source, UV detectors Thermo Scientific for Model 49.
O3 filter	O3 filter (MnO2) for O3 zeroing Thermo Scientific , PN 14697.
power supply board	Several protected voltages to the different elements LGM Ingénierie.
data acquisition system PC104	4 PC104 cards ; Diamond Systems : Athena CPU, Serial ports, Relays Ballard Technology : PM429 for Arinc-429.
flowmeters	CDK FSM series.
manifold	Teflon bottle connected with Teflon tubing Bioblock, 15032.
pressure sensor	Pressure monitoring of the O3 cells Thermo Scientific PN 9877.
flow controls	Teflon 1/8" tubes with length adjusted to provide 2 L min^{-1} for O3 path and 4 L min^{-1} for CO path (see blue and pink spiral tubing in Figure 4b).
Lower shelf	
CO device	CO absorption cell, IR source, IR detector with its thermal regulation card, CO cell motor Thermo Scientific for Model 48 Trace Level.
internal pump	KNF and NPK09.
O3 processing board	Control and signal acquisition/processing for O3 device (LGM Ingénierie).
CO processing board	Control and signal acquisition/processing for CO device (LGM Ingénierie).
O3 generator	Used for internal O3 calibration check (Thermo Scientific , FC001).
air drier	Nafion multi tube for drying the air prior to the CO cell (Permapure PD100T-12).
gas pressure regulator	Pressure regulation (2 bar) in the CO cell (Bronkhorst P702C-GAC-22-V-005A).
O3 filter	To remove atmospheric O3 before CO measurements (Thermo Scientific, PN 14697).
CO filter	Sofnocat catalyst from Molecular Products Ltd. filled in Swagelock 304L-HDF4-75-PD (75 cm^3).
electro-valves	3 Teflon valves for O3 (Teqcom), 1 Stainless Steel valve for CO (Thermo Scientific, 738).
GSM modem	Worldwide Data transmission, 4 bands Wavecom, Package 1 GSM Modem FastRack (Evolution planned for 2015 with 3G Modem).

Table 1: List and description of Package 1 sub-assemblies.

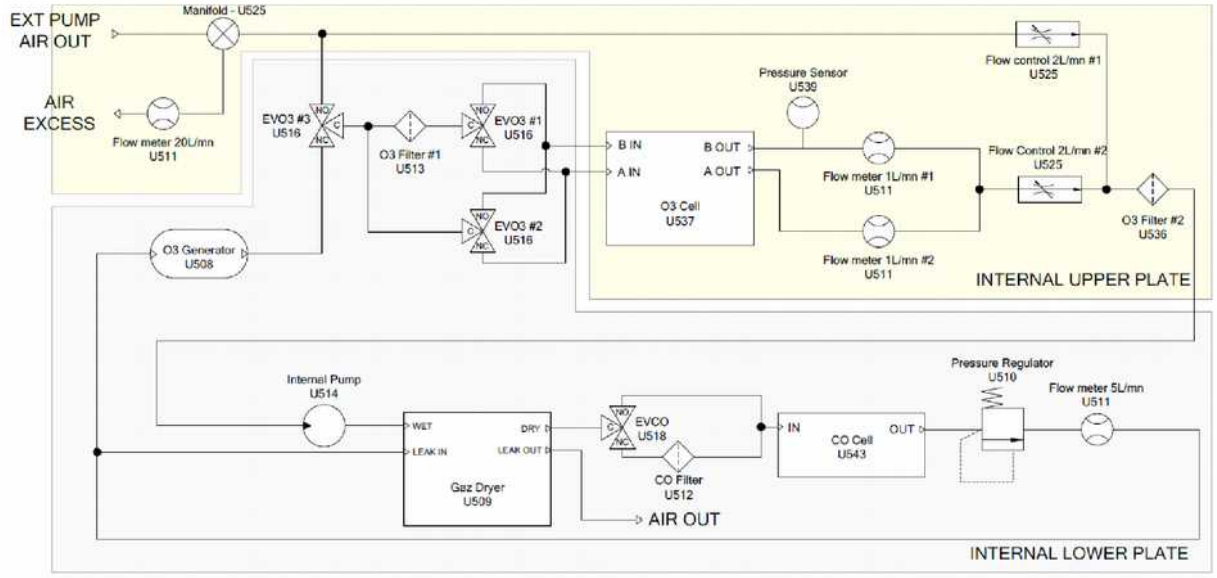

Figure 8: Flow diagram of IAGOS Package 1, showing all pneumatic connections for O3 and CO measurements.

O3 measurements

Schematic for O3 measurements is displayed on Figure 8. To prevent O3 destruction, all the lines up to internal pump are Teflon lines. Air and components for O3 measurements are at the cabin pressure and located upstream of the pump.

O3 measurements are performed by UV absorption at 254 nm. Two cells are used, one for ambient air containing O3, the other one with zero O3 air (removed by MnO3 filter). Each 4 seconds, the cells are switched. Pressure is measured in the O3 cells and O3 is automatically corrected for cabin pressure variations.

O3 is calculated on the Beer-Lambert law :

$$I / Io = e^{-KLC}$$

K = molecular absorption coefficient, 308 cm^{-1} (at 0°C and 1 bar)
L = cell length, 38 cm
C = ozone concentration in ppm
I = UV radiation measured in air containing O3
Io = UV radiation in air with no O3

O3 measurement uncertainty is : 4 seconds integration time, ± 2 ppb, ± 2%.

CO measurements

Schematic for CO measurements is displayed on Figure 8, CO line and components are located downstream to the internal pump. To increase the signal/noise ratio, the CO measurements cell is pressurised to 2 bars by the pressure regulator. This pressure difference also allow for drying the air by a Nafion tube.

CO measurements are performed by IR correlation at 4.6 µm, with an optimised IR detector cooled to -30°C. O3 and H2O are filtered prior to the measurements to prevent any interference with CO absorption. Periodic zeroing (10 to 20 minutes) of the instrument is made by passing air on Sofnocat filter to remove the CO.

CO is calculated on the Beer-Lambert law :

$$T = I / Io = e^{-axC}$$

T = Transmittance of light through the gas to the detector
a = specific CO molar absorption coefficient
x = path length
C = CO concentration in ppm
I = IR light intensity after absorption by CO
Io = IR light intensity at zero CO concentration

CO measurement uncertainty is : 30 seconds integration time, ± 5 ppb, ± 5%.

Instrument operation

In aircraft, the P1 operates fully automatically. All functions are controlled by the PC104 block PC using dedicated software. The PC104 Arinc-429 reception card is connected to the aircraft computer for acquisition and storage of the position, speed and meteorological parameters.

P1 is started when power is available in the aircraft, generally at least 2 hours before take-off, which is sufficient time for O3 UV lamp to start (20 minutes) and for the instrument to be almost stabilised in temperature, which is needed for IR CO measurements that are very sensitive to instrument internal temperature. P1 and Pump Box are cooled via IAGOS system extraction line to prevent overheating. In any case, if ambient temperature in the avionic compartment is above 45°C, the system is latched down and restarts when temperature is below 40°C.

Pressurisation pumps from Pump Box are started before take off when the aircraft moves from its parking position and stopped after landing. As one pump is normally sufficient for providing the requested flow in altitude (up to 41000 ft), only one pump is used (alternate every day) to increase the lifetime of the pumps.

Data acquisition starts during take-off (ground speed > 50 knots) and stops after landing (ground speed < 50 knots).

Using "Landing gear up and locked" and "Engine 2 oil pressure" analogue signals from the aircraft, the BCP with Laser for clouds measurements is started about 1 minute after take off and stopped when landing gear is descended prior to landing.

H2O sensor measurements (H2O and TAT) are analogue voltages, stored every 4 seconds.

Using "Weight on wheels" and "Forward cargo door opened" analogue signals from the aircraft, the GSM can be started and P1 flight data (about 1 Mb for each flight) are transmitted to CNRS reception centre. When Package2 are installed, Package2 data are also transmitted.

Data stored in-flight :

File Name *"Refvol"* is P1 SN	Content	Nb of columns	Frequency
A*AAAAMMJJHHMNSS{refVol}*.txt	Zeroing parameters of CO	8	10-20 min
C*AAAAMMJJHHMNSS{refVol}*.txt	BCP Data	17	4 sec
D*AAAAMMJJHHMNSS{refVol}*.txt	CO module functional parameters	11	1 min
E*AAAAMMJJHHMNSS{refVol}*.txt	Flight chronological events	2	n/a
H*AAAAMMJJHHMNSS{refVol}*.txt	H2O and T Voltages	3	4 sec
M*AAAAMMJJHHMNSS{refVol}*.txt	Aircraft Parameters	14	4 sec
S*AAAAMMJJHHMNSS{refVol}*.txt	Pump Box Flow	3	1 min
V*AAAAMMJJHHMNSS{refVol}*.txt	CO measurements	3	1 sec
X*AAAAMMJJHHMNSS{refVol}*.txt	O3 and O3 pressure measurements	3	4 sec
Y*AAAAMMJJHHMNSS{refVol}*.txt	O3 module functional parameters	11	1 min
Z*AAAAMMJJHHMNSS{refVol}*.txt	O3 in-flight calibration levels	9	2 hours

Table 2: Measured parameters stored during flights by the Package1. AAAA : Year, MM : Month, DD : Day, HHMMSS : Hour,Minutes, Seconds in UTC (Takeoff time), IN : Instrument Number (Package1).

Check of P1 functional parameters :

The p1 functional parameters are checked during the whole flight period, see tables below :

O3 parameter	Unit	Min	Max
Cells Pressure	mmHg	550	1000
Flow Cell A and B	l/min	0.75	1.10
Background level	ppb	-5	5
Calibration factor	-	0.9	1.1
Temperature Cells	°C	10	40
Temperature UV Lamp	°C	55	60
Temperature O3 Generator	°C	70	75
Detectors A and B	Hz	45 000	150 000
Calibration Level A	ppb	80	150
Calibration Level B	ppb	800	1500
Calibration Zero	ppb	-5	5

CO parameter	Unit	Min	Max
Zero Standard Deviation	ppb	0	15
Ratio Sample/Reference	-	1.13	1.18
Automatic Gain Control	Hz	150 000	250 000
Temperature Chamber	°C	10	45
Internal Temperature	°C	10	45
Flow	l/min	0.75	1.10
Calibration Factor	-	0.5	0.8
Bias Voltage	V	-125	-100
Cell Pressure from Regulator	V	4.1	4.3
IR detector temperature	V	1.0	1.1

If these parameters are in the range of normal operation, measurements are considered valid.
If one or some of the parameters are outside the range :

- corresponding measurement is set to default value

- or QA/QC report for the flight period gives a statement that measurements are valid (ex : flow meter is broken, but the pump is working)

Maintenance

P1 and Pump Box are normally installed on aircraft for a 6 months operation period. This period can be reduced if a failure occurs in the instruments and can be extended (up to 12 months) if the instrument works perfectly or if no spare is available. Aircraft equipped with IAGOS system can also be operated without P1 and Pump Box installed.

In order to receive a release to service certificate (EASA Form 1) after maintenance, all maintenance tasks must be performed and documented in compliance with predefined procedures set out in the contract between CNRS and the Maintenance Organisation (MO) responsible for continued airworthiness of the equipment. The maintenance are to be realised according to instruments manufacturer (LGM Ingénierie) documents: CMM.115279.500.0 for Package1 and CMM.115279.100 for Pump Box.

In addition to CMM which describe all maintenance actions and planning, specific maintenance actions can be performed in case of failure or mal-functioning of any component.

After flight operation period, O3 and CO calibrations are performed. Detailed maintenance actions are defined in the CMM, with the following main points:

- Pump box leak test : when inlet port is closed, flow must be 0
- Internal P1 pump leak check, membrane replacement or pump exchange
- Electro valves leak test, periodical replacement (6-12 months)
- O3 UV lamp control, adjustment to 150 kHz or replacement
- O3 and CO cells cleaning
- Tubing and manifold cleaning
- CO IR detector adjustment if necessary
- CO zeroing filter efficiency check

Before going back to operation, P1 and Pump Box are compared in Laboratory with a complete Mozaic system used as reference. Comparisons are done during several days and instruments are released to service when O3 difference is <1% and CO <5% during several days.

Calibration Methodology and Standards

Pre-flight calibration O3 & CO instruments

O3 and CO instruments of P1 are calibrated by CNRS prior to aircraft operation, when the instrument is new or after each maintenance.

In-flight calibration of O3 instruments

P1 is equipped with an internal O3 generator is used every 2 hours for instrument calibration check with O3 generated levels of 0, 100 and 500 ppb. This is done on ground and during cruise of the aircraft. As the precision of this in-flight calibration (15%) is much lower than the precision of the laboratory calibration (2%), it used only as a diagnostic of calibration drift in the instrument.

Post-flight calibration O3 & CO instruments

After each flight operation period, a post-flight calibration of O3 and CO instruments in the laboratory are performed by CNRS before any maintenance action has been done.

O3 laboratory calibration at CNRS

P1 is calibrated in O3 by comparison with a reference instrument Thermo Env. Model 49PS, at several levels of O3 to also check the linearity of the instrument within 1% : 0, 50, 100, 200, 300, 500 and 800 ppb.

According to EMEP procedures, this reference instrument is sent twice a year to French Laboratoire National d'Essais (LNE) for comparison with a NIST standard instrument. Pressure sensor on the O3 cells is also controlled via a reference pressure sensor.

QA/QC documents are provided for each flight period, from installation to removal form the aircraft. Table below is completed with calibration before and after the flight period.

O3	Ref Calibrator : Thermo 49CPS SNxxx Last check LNE : yyyy.mm.dd			
	Before Flight Period yyyy.mm.dd		After Flight Period yyyy.mm.dd	
Coeff O3				
Zero				
Lamp A				
Lamp B				
0 ppb				
50 ppb				
100 ppb				
200 ppb				
300 ppb				
500 ppb				
700 ppb				
800 ppb				
	Ref	Package1	Ref	Package1
Press. Sensor				

CO laboratory calibration at CNRS

Package1 is calibrated in CO using NIST referenced CO cylinders (CO in N2, 500 ppm) and a dilution system. Calibration is done at several levels of CO to also check the linearity of the instrument within 2-5% : 0, 250, 500, 750, 1000 and 1500 ppb.

Dilution system is sent twice a year to French Laboratoire National d'Essais (LNE) for flow meters controls.

QA/QC documents are provided for each flight period, from installation to removal form the aircraft. Table below is completed with calibration before and after the flight period.

CO	Ref CO Bottle : Concentration : Validity Date : from yyyy.mm.dd to yyyy.mm.dd Dilution system : Last check LNE : yyyy.mm.dd	
	Before Flight Period yyyy/mm/dd	After Flight Period yyyy/mm/dd
Coeff CO		
Flow (l/min)		
AGC		
S/R		
0 ppb		
250 ppb		
500 ppb		
750 ppb		
1000 ppb		
1500 ppb		
Check CO Filter		
Response time		

Data validation

After the flight operation period and the post-flight calibration, the data are set as final data if no calibration drift has been seen, which is normally the case as O3 and CO devices have been designed to be "very robust" (no significant drift of the calibration factor, 1% for O3, 5% for CO) over a 6 months period. All the instrument parameters are measured and stored every 1 min during the flights, to ensure for unexpected variations that can lead to data default values.

In case that a calibration discrepancy is found between pre and post flight calibration:
- for O3 measurements, the internal O3 calibration in flight gives the start time of the drift in calibration factor. The O3 calibration factor is interpolated linearly between the start of the drift and the end of the operation period and data are corrected. O3 data are set to default values in case of functional parameters are out of range.

- for CO measurements and as there is no calibration in flight, the CO calibration factor can be interpolated linearly between the beginning and the end of the operation period and data are corrected if drift is <5%. This normally does not happen, as all the CO parameters

are monitored in flight. CO data are set to default values in case of functional parameters are out of range.

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