STANDARD OPERATION PROCEDURE FOR THE IAGOS-CORE Package1 INSTRUMENT (P1)

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Preamble

This SOPs is covering:

1. Package 1 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 Package1

- CMM.115279.100 for Pump Box.

Rationale

Ozone 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 (about 20-50 ppb in remote areas), coming from stratospheric import, but also photo chemically produced from the anthropogenic emissions (COV, CO, CH4 and NOx). In polluted areas, its concentration can reach 100-200 ppb and is considered as toxic for humans and for vegetation.

Carbon monoxide (CO) is mainly produced by incomplete combustion of hydrocarbons from human activities and biomass burning. Its stratospheric concentrations are 10-50 ppb, in the remote atmosphere 50-100 ppb and its concentration in highly polluted areas can reach several ppmv. 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.

Description of method

Principle

The IAGOS Package1 is derived from the previous 2 Mozaic instruments, operated on Airbus aircraft since 1994 for O3 and 201 for CO. The 2 instruments are included into 1 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. Package1 is associated in the system with Pump Box, which contains 2 pressurisation pumps for driving air from to pitot tube to the atmospheric pressure.

Package1 also includes the acquisition/control of H2O and BCP instruments, acquisition of the aircraft parameters as position and meteorological parameters and communication with Package2 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.

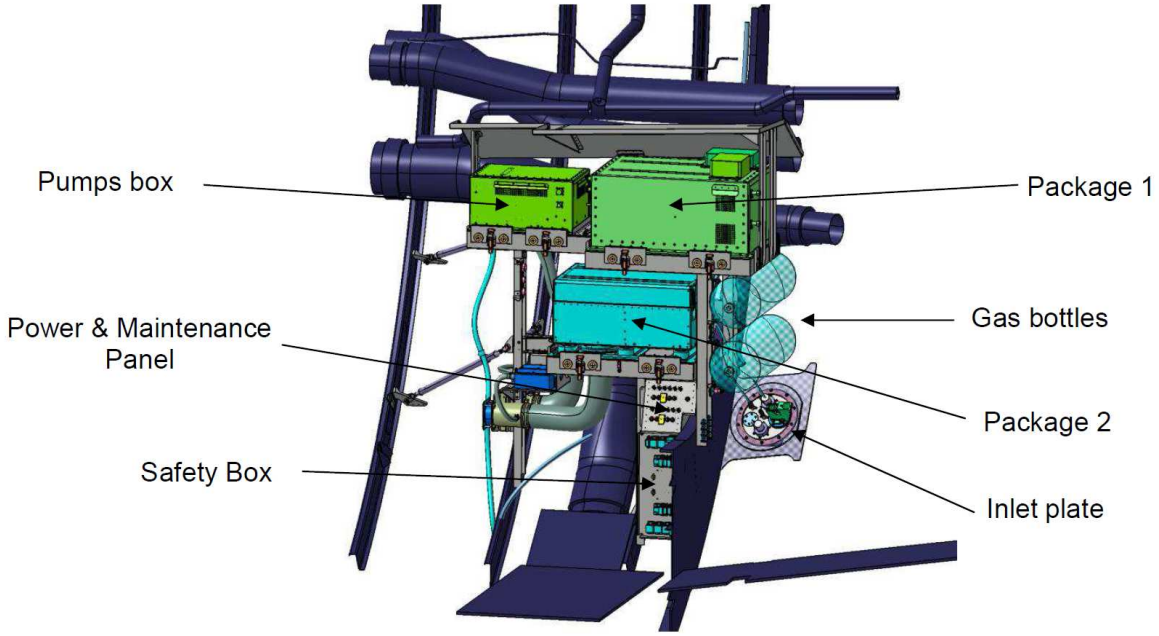


Figure 1: IAGOS installation aboard Airbus aircraft

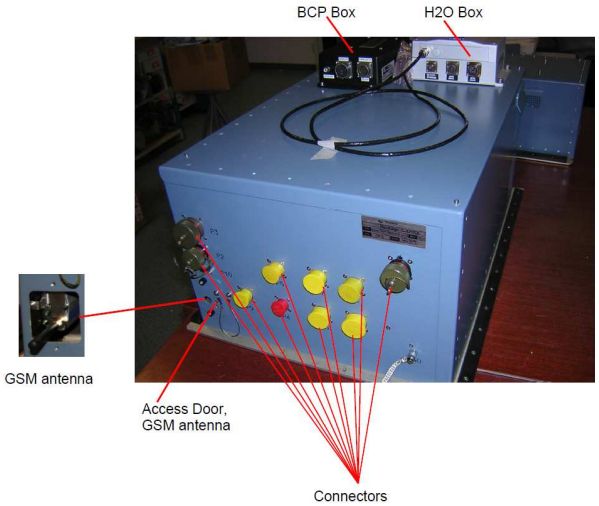


Figure 2 : Package1 external view

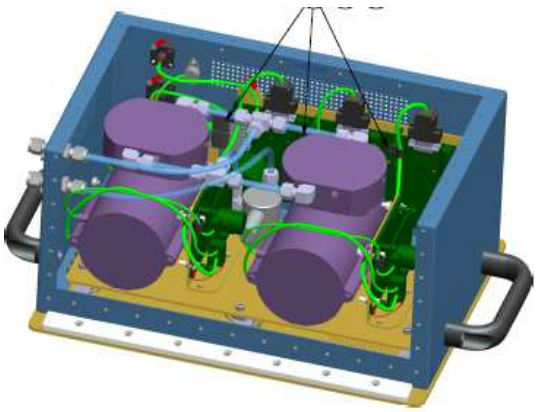


Figure 3 : Pump Box

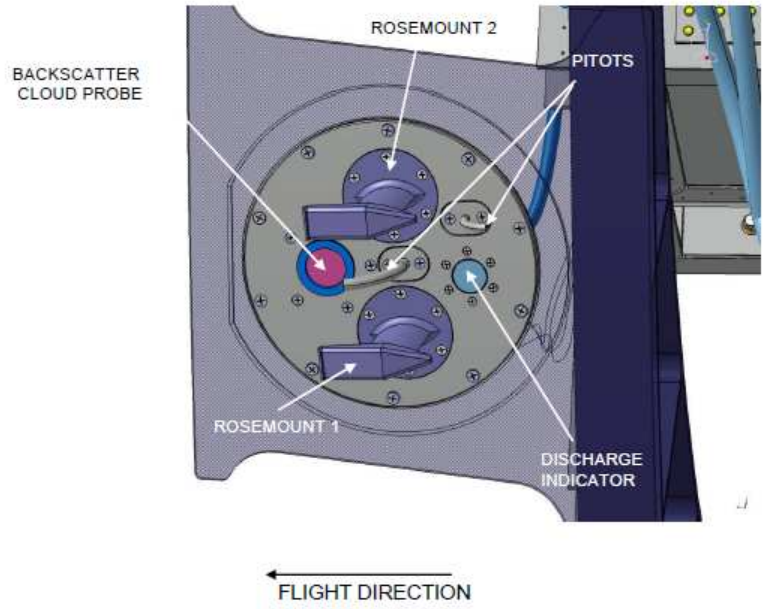


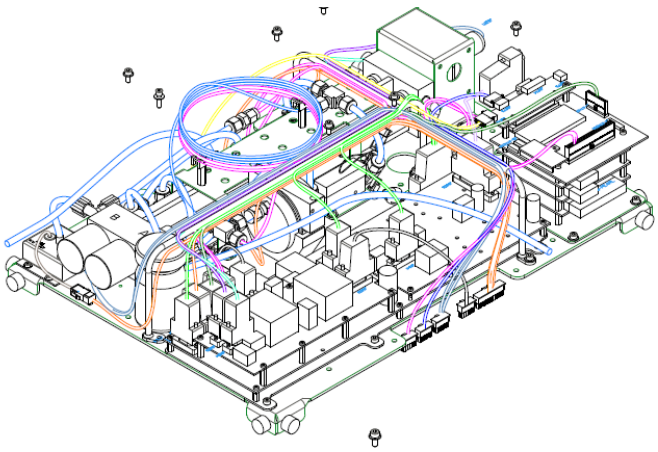
Figure 4 : IAGOS Inlet plate : Forward facing pitot for Package1 air, backward pitot for Package2 exhaust. Rosemount 1 holds the H2O sensor, Rosemount2 holds the Package2 inlet.

Air from inlet plate pitot tube (Figure pitot inlet) is driven by 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 Package1 is 4l/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 < 1 second and O3 loss on walls are expected to be < 1%. This is checked in laboratory after regular exchange of the equipments from aircraft.

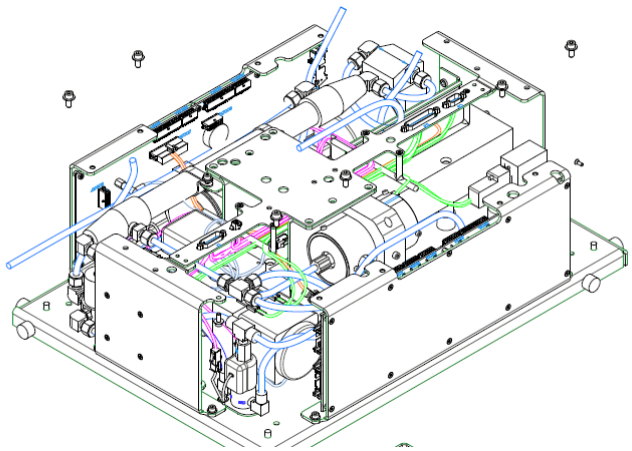
Description of Instrument

IAGOS Package1 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.



Upper Shelf :

- O3 absorption cells, UV source, detectors
- PC104 (4 cards)
- Power supply board
- O3 filter



Lower shelf :

- CO absorption cell, source and detector
- internal pressurisation pump and pressure regulator
- Nafion tube for air drying
- O3 generator, O3 and CO Electrovalves
- O3 and CO processing boards
- GSM Modem

Figure 5: IAGOS Package1 internal views

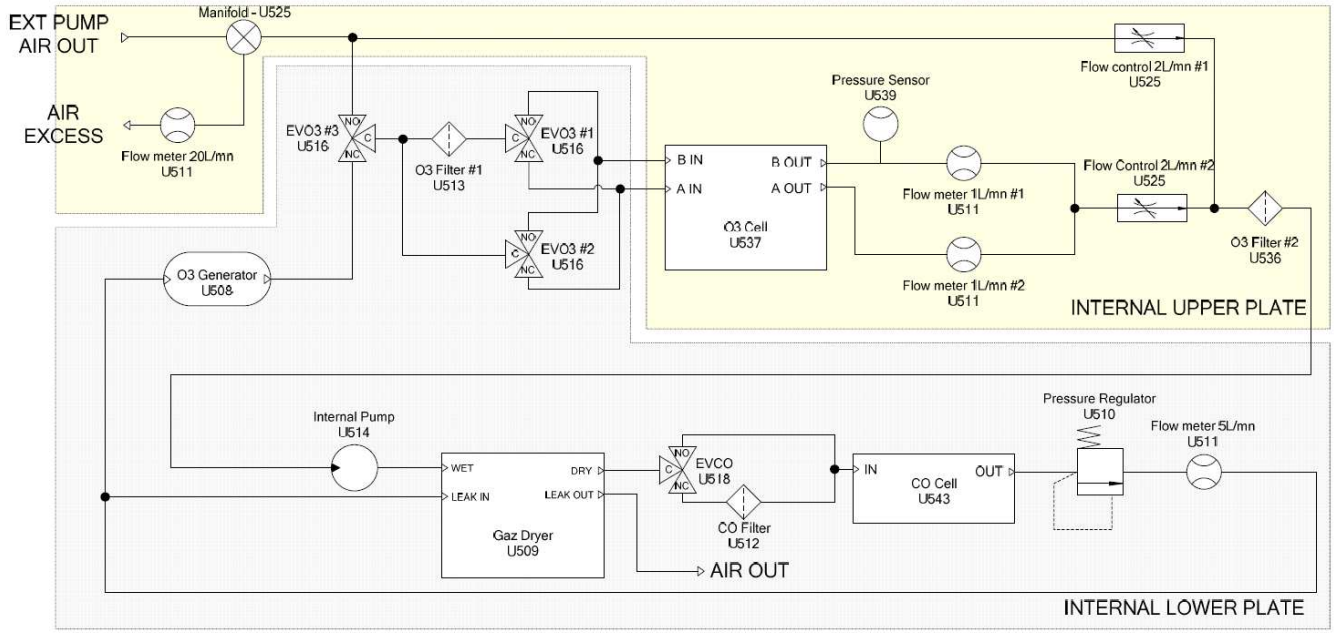


Figure 6: Flow diagram of IAGOS Package1, showing all pneumatic connections for O3 and CO measurments.

O3 measurements

Schematic for O3 measurements is displayed on Figure 6. 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 measurements specifications are : 4 seconds integration time, ± 2 ppb, ± 2%.

CO measurements

Schematic for CO measurements is displayed on Figure 6. 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 measurements specifications are : 30 seconds integration time, ± 5 ppb, ± 5%.

Instrument Operation

In aircraft, the Package1 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.

Package1 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, needed for IR CO measurements which are very sensitive to instrument internal temperature. Package1 and Pump Box are cooled via IAGOS system extraction line to prevent overheating. In any case, if ambient temperature in the avionics 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 in 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 > 50knots) and stops after landing (ground speed < 50knots).

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 Package1 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

Table1 : measured parameters stored in flight for P1.

Check of functional parameters

The 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, 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

Package1 and Pump Box are normally installed on aircraft for 6 months operation. 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 Package1 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 Package1 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, Package1 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 Standard

Pre-flight calibration O3 & CO instruments

O3 and CO instruments of Package1 are calibrated by CNRS prior to aircraft operation, when the instrument is new or after each maintenance.

In-flight calibration of O3 instruments

Package1 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

Package1 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		

Uncertainty Analysis

O3 measurements

Total uncertainty (4sec.) : ± 2 ppb ± 2%, which is the sum of :

- Thermo Model 49 : ± 2 ppb ± 1%

- Calibration Thermo Model 49PS : ± 1%

CO measurements

Total uncertainty (30 sec.) : ± 5 ppb ± 5%, which is the sum of :

- CO zero noise over 30 seconds : ± 5 ppb

- CO NIST traceable bottle 500 ppm : ± 2%

- dilution system : ± 2%

- Pressure regulator : ± 1%

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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