ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD)
PRODUCT USER MANUAL (PUM)

For

IASI L3 CO Climate Data Record (CDR O3M-543)

And

IASI L3 CO Interim Climate Data Record (ICDR O3M-359)

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DOCUMENT STATUS SHEET

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1.0	27/10/2022	First version of the IASI CO L3 CDR and ICDR product ATBD and PUM
1.1	26/04/2023	New version after reviewer's comments (MTR/ORR).

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1. SCOPE OF THE DOCUMENT

The objective of this document is to provide a description of the IASI CO Level-3 (L3) CO climate data record or CDR (with the AC-SAF nomenclature O3M-543) for Metop-A and Metop-B. EUMETSAT reprocessed the whole IASI CO data record and the CDR are available until December 2021. This was done to account for algorithm updates and to make the whole time series of IASI-CO, for the first time, homogeneous.

Metop C data (2019 onwards) is supposed to be running with the latest algorithm, and as such was not included in the reprocessing exercise. The notation "interim" climate data record, or ICDR (with the AC-SAF nomenclature O3M-359) is used to account for all CO products produced outside the CDR reprocessing exercise, i.e. the time series of IASI on Metop C (2019 onwards).

The IASI CO Level 3 products consist of monthly grids (1°x1°) and are produced from:

1- the IASI CO climate data record (CDR) Level 2 total column products reprocessed at EUMETSAT with the Fast Optimal Retrievals on Layers for IASI CO (FORLI-CO) algorithm (version 20151001), for Metop-A and B. FORLI-CO was developed by ULB in collaboration with LATMOS (Hurtmans et al., 2012).
2- The IASI CO interim climate data record (ICDR) Level 2 total column products retrieved in a near real time (NRT) at EUMETSAT with FORLI-CO version 20151001.

In short, both products are based on Level 2 CO data and follow the same algorithm described here and are generated at LATMOS within the framework of the AC SAF CDOP-4 project.

We note that the aim of this document is to describe the L2 to L3 algorithm basis. The reader can check the L2 (https://acsaf.org/docs/vr/Validation_Report_IASI_CO_Nov_2015.pdf for Metop-A&B and https://acsaf.org/docs/vr/Validation_Report_IASI-C_CO_May_2021.pdf for Metop-C) or L3 validation reports, reading notes, and product requirement tables for more in depth information on the products and their validation and inter-comparison.

2. THE IASI INSTRUMENT

IASI is an infrared Fourier transform spectrometer developed jointly by CNES (the French space agency) with support of the scientific community (for a review see Hilton et al. (2011)), and by EUMETSAT. IASI is mounted on-board the European polar-orbiting Metop satellite with the primary objective to improve numerical weather predictions, by measuring tropospheric temperature and humidity with high horizontal resolution and sampling, with 1 km vertical resolution, and with respectively 1 K and 10% accuracy (Camy-Peyret and Eyre, 1998). As a second priority IASI contributes to atmospheric composition measurements for climate and chemistry applications (Clerbaux et al., 2009).

To reach these two objectives, IASI measures the infrared radiation of the Earth's surface and of the atmosphere between 645 and 2760 cm^{-1} at nadir and along a 2200 km swath perpendicular to the satellite track. A total of 120 views are collected over the swath, divided as 30 arrays of 4 individual Field-of-views (FOVs) varying in size from 36 x π km^2 at nadir (circular 12 km diameter pixel) to 10 x 20 x π km^2 at the larger viewing angle (ellipse-shaped FOV at the end of the swath). IASI offers in this standard observing mode global coverage twice daily, with overpass times at around 9:30 and 21:30 mean local solar time. The very good spatial and temporal sampling of IASI is complemented by fairly high spectral and radiometric performances: the calibrated Level-1C (L1C) radiances are at 0.5 cm^{-1} apodized spectral resolution (the instrument achieves a 2 cm optical path difference), with an apodized noise that ranges below 2500 cm^{-1} between 0.1 and 0.2 K of a reference blackbody at 280 K (Hilton et al., 2011).

3. CARBON MONOXIDE TOTAL COLUMN RETRIEVAL FROM IASI

3.1 Level 1 to Level 2

The IASI CO total column Level-2 (L2) products are retrieved from the Level 1C (L1C) data using the FORLI algorithm. FORLI is a line-by-line radiative transfer model capable of processing in near-real-time the numerous radiance measurements made by the high-spatial and high-spectral resolution IASI, with the objective to provide global concentration distributions of atmospheric trace gases (Hurtmans et al. 2012). The algorithm is fully described in the SAF/AC/ULB/ATBD/001 (https://acsaf.org/docs/atbd/Algorithm_Theoretical_Basis_Document_IASI_CO_Feb_2014.pdf).

Previous validation studies using ground-based, aircraft and satellite data have shown that CO total columns from IASI are retrieved with an error generally below 10–15 % at mid and tropical latitudes, but can have larger errors in polar regions (George et al., 2009; Pommier et al., 2010; De Wachter et al., 2012; Kerzenmacher et al., 2012). Kerzenmacher et al. (2012) reported that the IASI CO total column products compare well on average with the co-located ground-based FTIR total columns and that there is no significant bias for the mean values at all stations.

Within the AC SAF project, the L2 carbon monoxide products serve as input to the generation of Level-3 (L3) carbon monoxide products (total column). Table 1 summarize the L2 data required for the creation of the gridded nadir carbon monoxide total column data set.

The L2 CO CDR/ICDR products have or are being validated within AC-SAF. The validation report, done by BIRA, covers the validation with ground based measurements (under review as of April 2023).

Table 1. Metop/IASI L2 data required as input to the generation of AC SAF carbon monoxide L3 product.

Originating system	IASI is on-board the EUMETSAT satellite Metop-A which was launched in October 2006. A second IASI instrument was launched in September 2012 on the Metop-B platform. A third IASI instrument was launched in November 2018 on the Metop-C platform. The IASI L2 data products are generated by applying the FORLI version 20151001 (Fast Optimal/Operational Retrieval on Layers for IASI) radiative transfer model and retrieval algorithm to L1C radiances to retrieve the carbon monoxide nadir vertical profile.
Data class	Earth Observation Data
Sensor type and key technical characteristics	see Section 1

Data availability & coverage	CDR: Start date: IASI-A: 10/07/2007, IASI-B: 20/02/2013 End date: IASI-A: 15/10/2021, IASI-B: 31/12/2021 ICDR: IASI-C data are available from September 20 2019 until present IASI-B data continuity from 01/01/2022 until present
Data quantity	Approximately 200 Gb / year for each sensor. For the CDRs in particular the total volume is: IASI-A: 4965 GB, IASI-B: 3180 GB
Data quality and reliability	For the L2 CDR data: the validation report done by BIRA is under review and show the following results: When compared with FTIR independent station measurements, all but one individual station has a bias estimate below the product required target accuracy of 12% for both the IASI A and IASI B CDRs. Only the Antarctic site at Arrival Heights exceeds the target accuracy slightly with 0.6%. The mean of the differences (being approx.. 4%) is smaller or of the same order as the reported FTIR systematic uncertainty. For the L2 NRT data: bias between IASI CO NRT data and MOZAIC measurements less than 13%.The overall bias (relative error) with FTIR measurements (https://acsaf.org/docs/vr/Validation_Report_IASI-C_CO_May_2021.pdf) is 3%.
Ordering and delivery mechanism	The L2 CDR data used to calculate the L3 CDR are available from EUMETSAT archive, under the doi: 10.15770/EUM_SAF_AC_0047 The NRT L2 CO data used to produce the L3 ICDR are available on EUMETcast and via the AC-SAF project page: https://acsaf.org/nrt_access.php

For the computation of the IASI L3 CO (see next Section), the IASI L2 CO data were filtered out in order to keep only CO measurements characterized by a good spectral fit based on quality descriptive and fit flags implemented in FORLI. Only the data associated with the parameter retrieval_quality_flag=2 in the L2 product (described in the CO L2 PUM section 5.3 https://acsaf.org/docs/pum/Product_User_Manual_IASI-C_CO_Nov_2021.pdf), which are considered as the most reliable data, were used for the production of the L3 data. For the CDR, a security check was applied to make sure that all total columns values are lower than 20e+18 molec.cm^{-2}.

3.2 Level-2 to Level-3

This section gives a description of the methodology used to calculate averaged carbon monoxide fields on a regular 1°x1° latitude-longitude grid and of its output files. Input that are provided are IASI/Metop-A, IASI/Metop-B and IASI/Metop-C L2 satellite measurements retrieved from FORLI-CO, output is consisted of 3 files in netcdf format (1 file per Metop). The averaged CO fields are calculated on the global scale, North pole and South pole included. In the CO L2 product, the total retrieval error on the CO total column is different from one pixel to another. When averaging over the 1°x1° grid, the total retrieval error of the different CO total columns within a grid is taken into account by giving more weight to the pixels associated with lowers errors.

For each month and each grid cell (*i,j*) (*i=1,…,360;j=1,…180*), the weighted mean (COgrid) and the corresponding error (Errorgrid) are given by Eq. 1 and Eq. 2, respectively:

$$COgrid(i,j) = \frac{\sum_l \frac{CO\_total\_column_l}{CO\_total\_column\_error_l^2}}{\sum_l \frac{1}{CO\_total\_column\_error_l^2}} \qquad \text{(Eq. 1)}$$

$$Errorgrid(i,j) = \sqrt{\frac{1}{\sum_l \frac{1}{CO\_total\_column\_error_l^2}}} \qquad \text{(Eq. 2)}$$

Where $CO\_total\_column\_error_l$ and $CO\_total\_column\_error_l$ are the retrieved carbon monoxide total column and the corresponding total retrieval error at pixel *l*, respectively. Both $CO\_total\_column\_$ and $CO\_total\_column\_error$ are calculated from the IASI CO L2 products.

The weighted average and the corresponding error are calculated for all pixels falling into the grid box during the month, independently of the number of observations per grid cell. They are provided for day and night time, separately in the L3 files. Day and night time data are determined with solar zenith angle to the sun <=90° and >90°, respectively. An example of spatial distribution of the CO total column L3 product is illustrated in Figure 1 for August 2021.

The IASI CO L3 product consists in 3 netcdf files (1 netcdf file per Meteop platform). The filename format for is as follow:

IASI_PLATFORM_L3_CO_COLUMN_YYYYMM_ULB-LATMOS_VERSION.nc

with PLATFORM=METOPA, METOPB or METOPC, YYYY=YEAR, MM=MONTH, VERSION=version of Eumetsat L2 product used for the generation of the L3 data

The current parameters included in NetCDF files are presented in Table 2. The METADATA information included in the netcdf files is provided in Table 3.

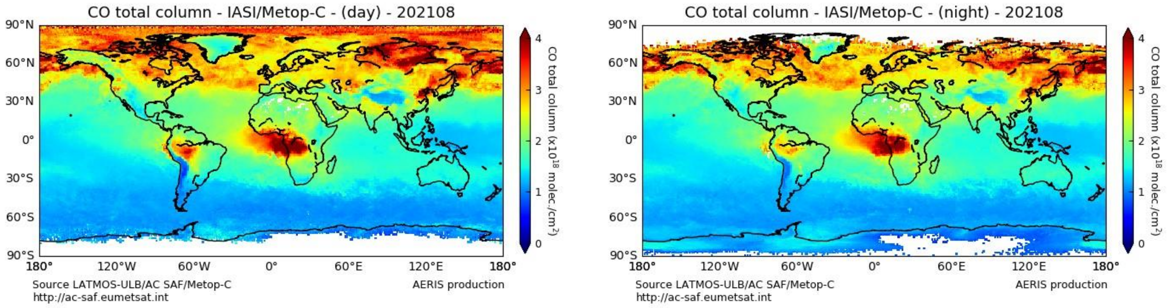

Figure 1: L3 mean carbon monoxide total column for day time (left) and nighttime (right) observations generated using the IASI/Metop-C L2 data.

Table 2: Dimension and description of the variables contained in the current IASI-A, IASI-B and IASI-C L3 carbon monoxide NetCDF files. N_{lat} and N_{lon} represents the number of latitude (N_{lat}=180) and longitude (N_{lon}=360), respectively.

Variable Name	Dimension	Unit	Description
latitude	N_{lat}	degree	latitude, from -90 (south) to +90 (north) given at gridcell centers
longitude	N_{lon}	degree	longitude, from -180 (west) to +180 (east) given at gridcell centers
COgridDAY	N_{lat} x N_{lon}	mol m^{-2}	weighted average of the carbon monoxide total columns for daytime observations
ErrorgridDAY	N_{lat} x N_{lon}	mol m^{-2}	error on the weighted average of the carbon monoxide total columns for day time observations
COgridNIGHT	N_{lat} x N_{lon}	mol m^{-2}	weighted average of the carbon monoxide total columns for nighttime observations
ErrorgridNIGHT	N_{lat} x N_{lon}	mol m^{-2}	error on the weighted average of the carbon monoxide total columns for nighttime observations

Table 3: METADATA information contained in the current IASI-A, IASI-B and IASI-C L3 CO NetCDF files.

Variable Name	Description
Disposition mode	O=operational; P=pre-operational, D=demontrastional
InstrumentID	IASI
ProcessingLevel	03
ProcessingMode	N=nominal; R=reprocessed
ProcessingTime	Time of data processing
ProductAlgorithmVersion	Version of algorithm version
ProductID	O3M-359
ProductType	IASI_L3_CO
SatelliteID	M02=Metop-A, M01=Metop-B, M03=Metop-C
SensingStartTime	time of sensing start
SensingEndTime	Time of sensing end
StartOrbitNumber	Number of starting orbit

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5. ACRONYMS

Acronym	Definition
AC SAF	Atmospheric Composition Monitoring Satellite Application Facility
ATBD	Algorithm Theoretical Basis Document
CDR	Climate Data Record
ICDR	Interim Climate Data Record
CDOP	Continuous Development and Operations Phase
CNES	Centre National d'Études Spatiales (France)
CO	Carbon Monoxide
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FORLI	Fast Optimal/Operational Retrieval on Layers for IASI
FOV	Field Of View
IASI	Infrared Atmospheric Sounding Interferometer
IR	Infra-Red
LATMOS	Laboratoire Atmosphères et Observations Spatiales
Metop	Meteorological Operational Platform (EUMETSAT)
NetCDF	Network Common Data Form (data file format)
NRT	Near real time
PUM	Product User Manual