S2 MPC

Level 2A Input Output Data Definition

Ref. S2-PDGS-MPC-L2A-IODD-2.8

The power of innovation

Authors Table

	Name	Company	Responsibility	Date	Signature
Written by	U. Müller-Wilm	TPZD	Project Manager L2A Maintenance	2018-01-29	Uwe Müller-Wilm Digitally signed by Uwe Müller-Wilm Date: 2019.01.29 17:31:57 +01'00'
Verified by	O Devignot	CS	Quality Manager	2018-01-29	
Approved by	L. Pessiot	CS	Service Manager	2018-01-29	

Change Log

Issue	Date	Reason for change	Pages(s)/Section(s)
1.0	2014-03-27	Creation	
2.3	2016-11-25	Update for Sen2Cor V.2.3.0	All pages
2.4	2017-07-18	Update for Sen2Cor V.2.4.0	All pages
2.6	2018-02-23	Updates for Sen2Cor V.2.6.1: Updated all GIPP Schemes and description Resolved RIDS from TAS as listed below	See attached PDF in section 3.4
		Fig.6: This figure indicates a GML-JPEG2000 format for the images (understood as a GML geotag in JPEG2000 header) while table 25 indicates only JPEG2000. Please clarify.	Fig. 6 removed and Table updated. Section 2.4.2 contains a reference to [S2-PDGS-MPC-L2A-PFS], which contains the specification of the image formats
		Section Atmospheric Correction and Scene Classification : with GIPP AC and SC provided through expert level, please confirm the Sen2Cor ignore the Atmospheric_Correction and Scene_Classification tags in the $SEN2COR_HOME/cfg/L2A_GIPP.xml	Sections 3.1, 3.2 updated to contain the necessary information
		The GIP_L2A_PB does not seem to be described	Section 3.3 inserted to contain the necessary information
		Added section on Auxiliary Data for Scene Classification	Section 2.2.4
		Updated Ozone Content GIPP according to review comments, J. Louis	Section 2.3.22.2.3

Issue	Date	Reason for change	Pages(s)/Section(s)
2.7	2018-09-21	Updates for Sen2Cor V.2.7.0: added GIPPs for Database compression factor and disabling of terrain correction with DEM. Added further command line parameters for determining database location.	Sections 2.1.2, 2.1.6
2.8	2019-01-29	Updates for Sen2Cor V.2.8.0: removed parameter Nr_Processes and added parameters Nr_Treads and Ac_Dem_P2p_Val	Section 2.1.2 and 3.4

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1. Introduction

1.1 Purpose of the document

This Document lists the Input Output Data Definitions of the Sen2Cor application.

1.2 Document structure

This IODD lists for each of the following processes:

- Scene Classification
- Atmospheric Correction, with sub-processes:
  - Aerosol Optical Thickness Retrieval;
  - Water Vapour retrieval;
  - Cirrus Correction;
  - Terrain Correction;
  - Surface Reflectance,

the corresponding Input and Output data separated for the following four criteria:

- Input Data;
- Ground Image Processing Parameter (GIPP);
- Metadata;
- Output Data.

1.3 References

Document ID	Description	Version
S2-PDGS-MPC-L2A-PFS	Sentinel-2 MSI – Product Format Specification	14.5
S2-PDGS-MPC-L2A-SUM	Sentinel-2 MSI – Level 2A Prototype Processor Installation and User Manual	2.8.0
S2-PDGS-MPC-L2A-ATBD	Sentinel-2 MSI - Level 2A Products, Algorithm Theoretical Basis Document	2.1
S2-PDGS-MPC-L2A-DPM	Sentinel-2 MSI – Level 2A Detailed Processing Model	1.0
S2-PDD	GMES Space Component – Sentinel-2 Payload Data Ground Segment (PDGS), Product Definition Document	2.3
S2-PSD	Sentinel-2 Products Specification Document	14.5

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2. Level-2A Products Overview

2.1 Common Data

This section lists all IO data and parameters which are related to the basic operation of the processor.

2.1.1 Input Data

The input data on pixel level and the L1C product formats are described in detail in [L2A-PFS], see reference above.

Table 1 – L1C Image data specification

Name	Level-1C
Parent Product	L1C, TOA Reflectance
Coverage	Regional
Packaging	Tiles (same area coverage as Level 1C input data)
Geo-location accuracy	Identical to the level 1C geo-location performance
Frequency	Variable upon Level 1C products availability

<table>
<tr><th>Name</th><th>Level-1C</th></tr>
<tr><td>Format</td><td>Kakadu 7.4, details @60 m processing:<pre>
Codestream, import Band1, 60m res:

    SOC marker segment @ (1927, 0)
    SIZ marker segment @ (1929, 41)
        Profile: no profile
        Reference Grid Height, Width: (1830 x 1830)
        Vertical, Horizontal Reference Grid Offset: (0 x 0)
        Reference Tile Height, Width: (192 x 192)
        Vertical, Horizontal Reference Tile Offset: (0 x 0)
        Bitdepth: (15,)
        Signed: (False,)
        Vertical, Horizontal Subsampling: ((1, 1),)
    COD marker segment @ (1972, 17)
        Coding style:
            Entropy coder, with partitions
            SOP marker segments: False
            EPH marker segments: False
        Coding style parameters:
            Progression order: LRCP
            Number of layers: 1
            Multiple component transformation usage: no transform specified
            Number of resolutions: 5
            Code block height, width: (4 x 4)
            Wavelet transform: 5-3 reversible
            Precinct size: ((64, 64),(64, 64),(64, 64),(64, 64),(64, 64))
            Code block context:
                Selective arithmetic coding bypass: False
                Reset context probabilities on coding pass boundaries: False
                Termination on each coding pass: False
                Vertically stripe causal context: False
                Predictable termination: False
                Segmentation symbols: False
    QCD marker segment @ (1991, 16)
        Quantization style: no quantization, 1 guard bits
        Step size: [(0, 16), (0, 17), (0, 17), (0, 18), (0, 17), (0, 17),
(0, 18), (0, 17), (0, 17), (0, 17), (0, 16), (0, 16), (0, 17)]
    CME marker segment @ (2009, 15)
        "Kakadu-v7.4"
    CME marker segment @ (2026, 92)
        "Kdu-Layer-Info: log_2{Delta-D(squared-error)/Delta-L(bytes)},
         L(bytes) -192.0, 3.8e+06"
</pre></td></tr>
<tr><td>Unit</td><td>Dimensionless, Unsigned Integer 15 bit</td></tr>
</table>

Name	Level-1C
Calibration and Range	1 / 10000: i.e.: Digital Numbers 0 : 10000, representing radiometric reflectance values from 0.0 to 1.0
Sampling	16 bit/pixel
Channels and Resolution	**Resolution (m)**
B1 (443nm)	60
B2 (490nm)	10
B3 (560nm)	10
B4 (665nm)	10
B5 (705nm)	20
B6 (740nm)	20
B7 (783nm)	20
B8 (842nm)	10
B8a (865nm)	20
B9 (945nm)	60
B10 (1375)	60
B11 (1610nm)	20
B12 (2190nm)	20

2.1.2 GIPP

GIPPs are configured in an XML file named L2A_GIPP.xml, located in the <cfg> subdirectory of the Sen2Cor home directory which is specified by the environment variable $SEN2COR_HOME, and can be configured by the user (exceptions which should not be configured by standard users are marked with an asterisk (*).

and subsequently copied into the AUX_DATA subfolder of the corresponding granule for documentation purposes.

Within this IODD the GIPP are listed within their current processing context. Table 2 lists only the GIPP which are common for the overall processing. Specific

GIPPs are listed in the corresponding subsections separated for each sub processing step. Figure 1 shows the GIPP of the Common Section.

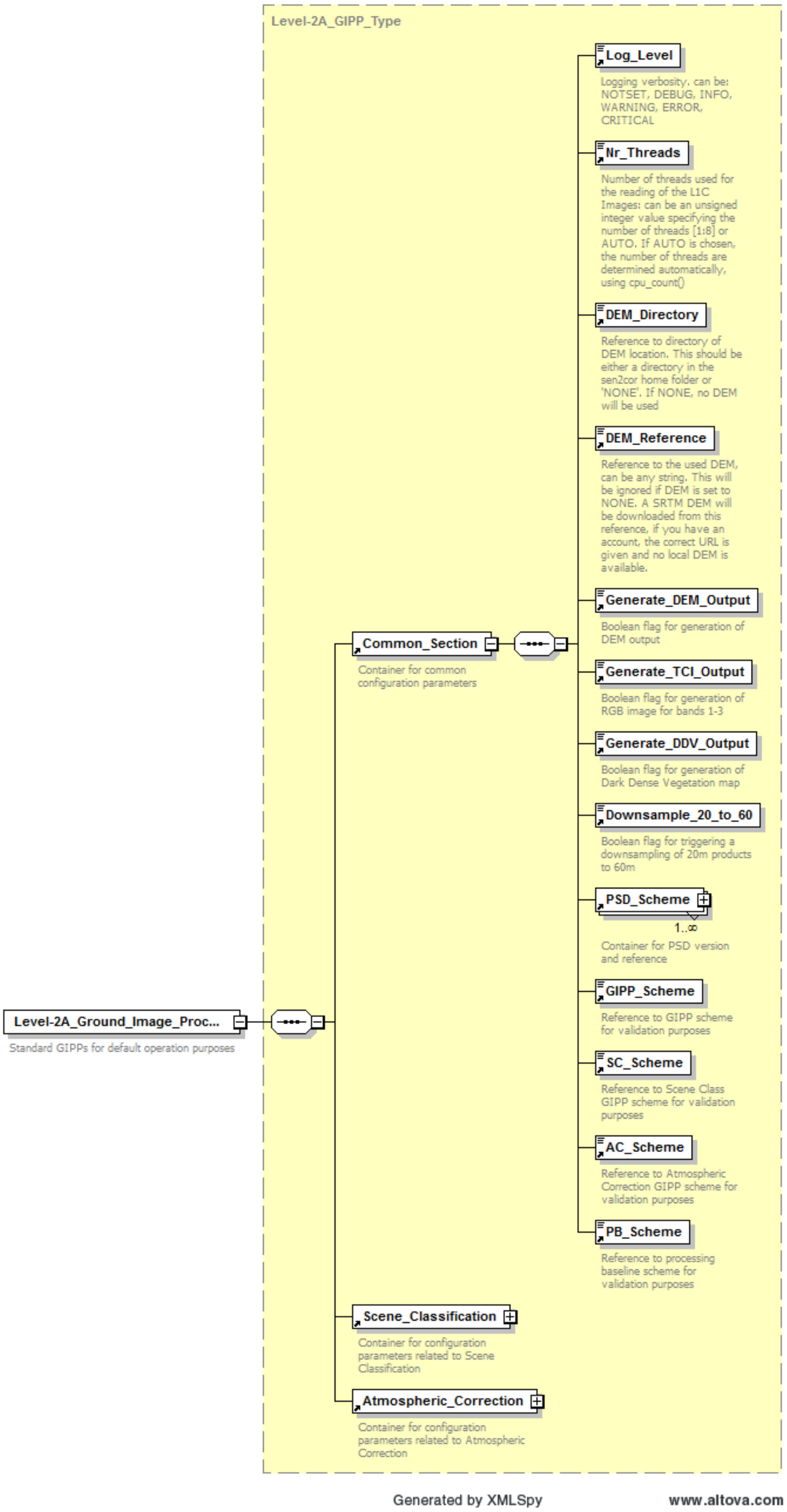


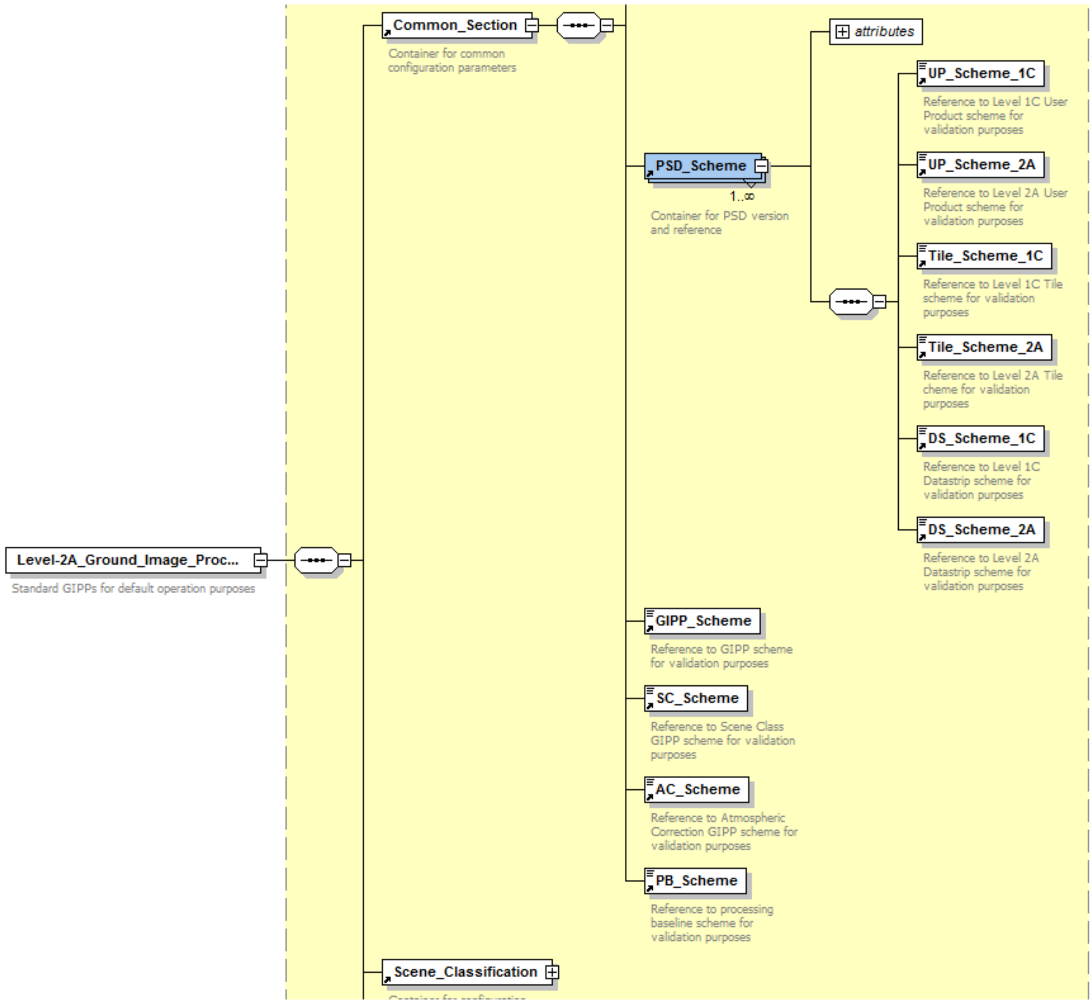
Figure 1 – GIPP of Common Section

Table 2 – Common GIPP

Field Name	Documentation	Type
Log_Level	Verbosity level of the tracing output, located in the GRANULE/<GRANULE>/QI_DATA folder.	Enumerator: NOTSET, DEBUG, INFO, WARNING, ERROR, CRITICAL
Nr_Threads	This parameter allowing the usage of multithreading to speed up the reading of the L1C input images. above). It is set to AUTO by default, which detects the amount of usable threads by calling cpu_count(). If the user does not want this feature or want to set the amount of threads individually, the parameter can be changed between a value of 1 (which is single thread processing, as before) up to 8.	Choice: AUTO or: Unsigned Integer Value [1:8]
DEM_Directory	Location of optional Digital Elevation Map: can be either a directory in the sen2cor home folder or 'NONE'. If NONE, no DEM will be used. Example: 'dem/srtm'. DEM will be searched in: <SEN2COR_HOME>/dem/srtm	Choice: NONE or String (relative directory path)
DEM_Reference	If no suitable DEM is found in the DEM directory, the processor tries to download a DEM from the given reference. Currently only the CGIAR 90 m resolution DEMs are supported, which can be downloaded from: http://data_public:GDdci@data.cgiar-csi.org/srtm/tiles/GeoTIFF	URL
Generate_DEM_Output	FALSE: no DEM output, TRUE: store DEM in the AUX data directory	FALSE or TRUE
Generate_TCI_Output	FALSE: no TCI output, TRUE: store TCI in the IMAGE data directory	FALSE or TRUE
Generate_DDV_Output	FALSE: no DDV output, TRUE: store DDV in the QI_DATA directory	FALSE or TRUE

Field Name	Documentation	Type
Downsample_20_ to_60	TRUE: create additional 60m bands when 20m is processed	FALSE or TRUE
PSD_Scheme (*)	List of supported PSD Versions: V 14.2 – V.14.5 (Sen2Cor 2.8.0) Properties: • Version: The PSD Versions • PSD_Reference: the names of the available PSD schemes Names: UP_Scheme_1C: <name> UP_Scheme_1C: <name> Tile_Scheme_1C <name> Tile_Scheme_2A <name> DS_Scheme_1C: <name> DS_Scheme_2A: <name> Remark: these schemes are used for validation of the in- and output metadata. The configuration should not be changed by the user	XML List of strings
GIPP_Scheme (*)	Name of the xsd scheme for the base GIPP (this file, used for validation purposes)	String (filename). Default is L2A_GIPP.xsd
SC_Scheme (*)	Name of the xsd scheme for the expert calibration GIPP for scene classification (used for validation purposes, not foreseen to be configured by standard uses).	String (filename). Default is: L2A_CAL_SC_GIPP.xsd
AC_Scheme (*)	Name of the xsd scheme for the expert calibration GIPP for the atmospheric correction (used for validation purposes, not foreseen to be configured by standard uses).	String (filename). Default is:L2A_CAL_AC_GIPP.xsd
PB_Scheme (*)	Name of the xsd scheme for the Processing Baseline.	String (filename). Default is:L2A_PB-_GIPP.xsd

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.



For a full list of all GIPPs including their types values and ranges, consult the embedded PDF in section 3.4.

2.1.3 Metadata

Metadata are read out directly from the Level 2A Tile metadata XML file after being generated from the corresponding Level-1C User product.

Table 3 – Metadata input fields (see L2A-PFS for details)

Field Name	Documentation	Type
ZENITH_ANGLE	Incidence angles	Floating point 32 bit
AZIMUTH_ANGLE	Incidence angles	Floating point 32 bit
Zenith	Grids for Zenith Viewing Incidence Angle values (0 - 70°)	Floating point array 32 bit

Field Name	Documentation	Type
Azimuth	Grids for Azimuth Viewing Incidence Angle values (0 – 360°)	Floating point array 32 bit
QUANTIFICATION_VALUE	Digital Number of L1C Input bands, dimensionless, 0 :10.000 corresponds to TOA reflectance 0 : 1	Unsigned Integer
ECMWF_DATA_REFERENCE	Filename of the ECMWF data located in the GRANULE/AUX_DATA folder	String (filename)

2.1.4 Auxiliary Data

Table 4 – Aux_Data

Field Name	Documentation	Type
DEM	Digital Elevation Map, user configurable image data located in $SEN2COR_HOME, directory, configurable via L2A_GIPP, see Table 2 Unit: m	Tiff or Dted format (dt1) Integer, 16 bit As OpenJPEG is only able to store unsigned integer values, an offset of +10.000 is applied to each DEM allowing negative heights. The scale of the DEM is thus (meter – 10.000).
AUX_ECMWF, located in the GRANULE/AUX_DATA folder	Raster data of Block Size 9:9 in GRIB Format, 3 Bands, specifying: B1: Precipitable water content [kg/m^2] B2: Mean sea level pressure [Pa] B3: Total column ozone Dobson [kg/m^2]	Float 64

2.1.5 Output Data

Outputs are classified specific for the corresponding procedures in the equivalent sections for the sub modules.

2.1.6 Command Line Parameters

Command Line Parameters ("PDGS" mode using L1C Datastrip and L1C Tile as input_dir)

```
L2A_Process --help
usage: L2A_Process.py [-h] [--mode MODE] [--resolution {10,20,60}]
                      [--datastrip DATASTRIP] [--tile TILE]
                      [--output_dir OUTPUT_DIR] [--work_dir WORK_DIR]
                      [--img_database_dir IMG_DATABASE_DIR]
                      [--res_database_dir RES_DATABASE_DIR]
                      [--processing_centre PROCESSING_CENTRE]
                      [--archiving_centre ARCHIVING_CENTRE]
                      [--processing_baseline PROCESSING_BASELINE] [--raw]
                      [--tif] [--sc_only] [--cr_only] [--debug]
                      [--GIP_L2A GIP_L2A] [--GIP_L2A_SC GIP_L2A_SC]
                      [--GIP_L2A_AC GIP_L2A_AC] [--GIP_L2A_PB GIP_L2A_PB]
                      input_dir

Sentinel-2 Level 2A Processor (Sen2Cor). Version: 2.8.0, created: 2019.01.20, supporting
Level-1C product version 14.2 - 14.5.

positional arguments:
  input_dir             Directory of Level-1C input

optional arguments:
  -h, --help            show this help message and exit
  --mode MODE           Mode: generate_datastrip, process_tile
  --resolution {10,20,60}
                        Target resolution, can be 10, 20 or 60m. If omitted,
                        only 20 and 10m resolutions will be processed
  --datastrip DATASTRIP
                        Datastrip folder
  --tile TILE           Tile folder
  --output_dir OUTPUT_DIR
                        Output directory
  --work_dir WORK_DIR   Work directory
  --img_database_dir IMG_DATABASE_DIR
                        Database directory for L1C input images
  --res_database_dir RES_DATABASE_DIR
                        Database directory for results and temporary products
  --processing_centre PROCESSING_CENTRE
                        Processing centre as regex: ^[A-Z_]{4}$, e.g "SGS_"
  --archiving_centre ARCHIVING_CENTRE
                        Archiving centre as regex: ^[A-Z_]{4}$, e.g. "SGS_"
  --processing_baseline PROCESSING_BASELINE
                        Processing baseline in the format: "dd.dd", where
                        d=[0:9]
  --raw                 Export raw images in rawl format with ENVI hdr
  --tif                 Export raw images in TIFF format instead of JPEG-2000
  --sc_only             Performs only the scene classification at 60 or 20m
                        resolution
  --cr_only             Performs only the creation of the L2A product tree, no
                        processing
  --debug               Performs in debug mode
  --GIP_L2A GIP_L2A     Select the user GIPP
  --GIP_L2A_SC GIP_L2A_SC
                        Select the scene classification GIPP
  --GIP_L2A_AC GIP_L2A_AC
                        Select the atmospheric correction GIPP
  --GIP_L2A_PB GIP_L2A_PB
                        Select the processing baseline GIPP
```

Command Line Parameters ("Toolbox" mode using L1C product as input_dir)

```
L2A_Process --help
usage: L2A_Process.py [-h] [--resolution {10,20,60}]
                      [--output_dir OUTPUT_DIR]
                      [--sc_only] [--cr_only] [--refresh]
                      [--GIP_L2A GIP_L2A] [--GIP_L2A_SC GIP_L2A_SC]
                      [--GIP_L2A_AC GIP_L2A_AC] input_dir

positional arguments:
  input_dir             Directory of Level-1C input

optional arguments:
  -h, --help            show this help message and exit
  --resolution {10,20,60}
                        Target resolution, can be 10, 20 or 60m. If omitted,
                        all resolutions will be processed
  --output_dir OUTPUT_DIR
                        Output directory (a full path) for Level 2A product. If not set, the
product will be located in the same directory as the input product.
  --tif                 Export raw images in TIFF format instead of JPEG-2000
  --sc_only             Performs only the scene classification at 60 or 20m
                        resolution
  --cr_only             Performs only the creation of the L2A product tree, no
processing
  --GIP_L2A GIP_L2A     Select the user GIPP (a filename with full path)
  --GIP_L2A_SC GIP_L2A_SC
                        Select the scene classification GIPP (a filename with full path)
  --GIP_L2A_AC GIP_L2A_AC
                        Select the atmospheric correction GIPP (a filename with full path)
  --GIP_L2A_PB GIP_L2A_PB
                        Select the processing baseline GIPP (a filename with full path)
```

2.2 Scene Classification

2.2.1 Input Data

L1C Image data as specified in Section 2.1.1, resampled to the requested resolution of 60, 20, 10 m.

2.2.2 GIPP

Figure 2 shows the GIPP of the Scene Classification Module

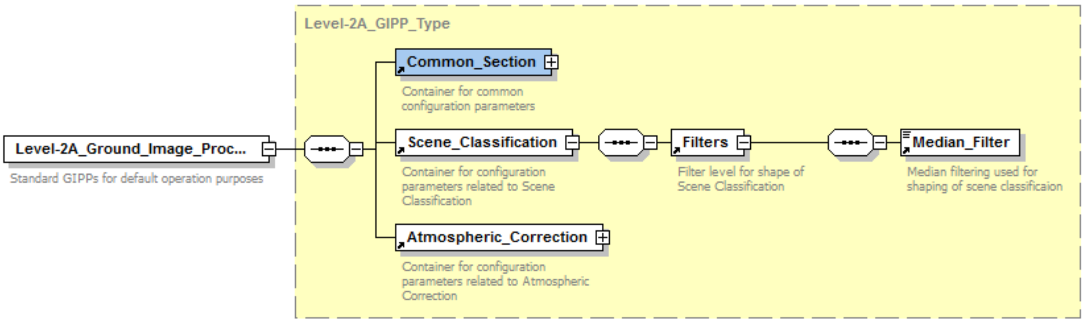


Figure 2 – GIPP of Scene Classification

Table 5 – GIPP

Field Name	Documentation	Type
Median_Filter	Digital Filter for smoothing of Classification map.	Unsigned Integer, recommended values 0:3, Default: 0

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.

2.2.2.1 Expert Level

GIPP for the Scene Classification on Expert Level are separated from the standard User level and are collected in a different file, named L2A_CAL_SC_GIPP.xml. Whereas L2A_GIPP.xml is a pure user configuration file and thus is available for a standard user, the Expert level GIPPs are reserved for testing and calibration campaigns. Wrong calibrations might lead to heavy performance artefacts. The description of these parameters is thus postponed to Section 3.1 and standard users are warned to remain these calibration parameters untouched. For a full list of all GIPPs including their types, values and ranges, consult the embedded PDF in section 3.4.

2.2.3 Metadata

Quality Information data on Tile level are part of the Tile metadata as summarized for Figure 3. The Entries represent the percentage of classified pixels as listed for Table 8, related to the total amount of data pixels (100 %).

Quality Information data on User Product level are part of the User product Metadata. The figures are an average over all tiles processed for the according product. The structure follows the QI Data on tile level as displayed in Figure 3.

Additional metadata are specified in Section 2.1.3, Table 3.

2.2.4 Auxiliary Data

The ESACCI-LC for Sen2Cor data package is prepared for users of Sen2Cor version starting with sen2Cor 2.5.5 which want to benefit from the last improvements of Sen2Cor Cloud Screening and Classification module. This auxiliary data information is used in Sen2Cor to improve the accuracy of Sen2Cor classification over water, urban and bare areas and also to have a better handling of false detection of snow pixels.

Users of Sen2Cor version ≥ 2.5 should download this ESACCI-LC for Sen2Cor data package (ESACCI-LC-L4-ALL-FOR-SEN2COR.zip) from this location:

http://maps.elie.ucl.ac.be/CCI/viewer/download.php

This zip file shall then be extracted at this location of Sen2Cor installation: '***$SEN2COR_BIN/aux_data/.***' It contains two files and one directory:

- *ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif*
- *ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif*
- *ESACCI-LC-L4-Snow-Cond-500m-P13Y7D-2000-2012-v2.0*

Example on a Ubuntu (Linux) installation:

$ ls Sen2Cor-02.08.00-Linux64/lib/python2.7/site-packages/sen2cor/aux_data

ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif

ESACCI-LC-L4-Snow-Cond-500m-P13Y7D-2000-2012-v2.0

ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif

Example on a Windows7 installation:

>dir Sen2Cor-02.08.00-Linux64/lib/python2.7/site-packages/sen2cor/aux_data

ESACCI-LC-L4-LCCS-Map-300m-P1Y-2015-v2.0.7.tif

ESACCI-LC-L4-Snow-Cond-500m-P13Y7D-2000-2012-v2.0

ESACCI-LC-L4-WB-Map-150m-P13Y-2000-v4.0.tif

Note2: Please note that it is possible to use symbolic links in this aux_data folder if you prefer to copy those auxiliary files to another data folder. (unix command: ln –s, windows command: mklink)

Note1: Please note that a Digital Elevation Model (DEM) is a pre-requisite for using ESACCI_LC information in the Scene Classification algorithm. In the case SRTM DEM is used, latitudes higher > 60 deg N (and lower < 60 deg S) are not covered by the SRTM DEM, therefore no ESACCI_LC information will be used for these latitudes. Standard Scene Classification algorithm will then be applied.

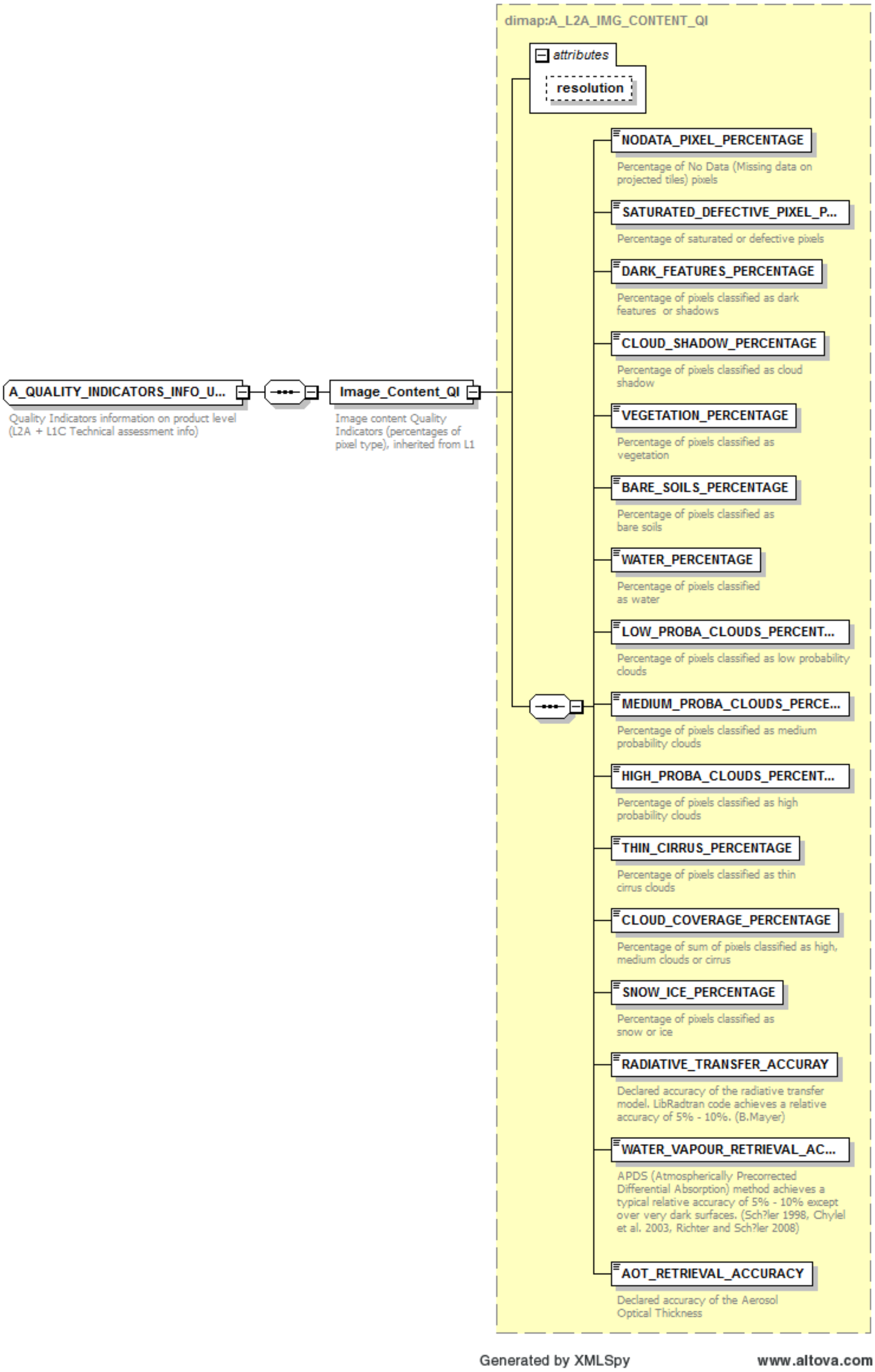


Figure 3 – QI Data of Tile and User Product Metadata

2.2.5 Output Data

Table 6 – Cloud Probability map

Cloud Probability [QI Data]	
Unit	percentage
Range	0 - 100
Sampling	8 bit/sample
Resolution	60 m, 20 m

Table 7 – Snow Probability map

Snow Probability [QI Data]	
Unit	percentage
Range	0 – 100
Sampling	8 bit/sample
Resolution	60 m, 20 m

Table 8 – Scene Classification

Scene Classification [Image Data]	
Unit	enumeration

Scene Classification [Image Data]	
Range	0 — No Data (Missing data on projected tiles) (black) 1 — Saturated or defective pixel (red) 2 — Dark features / Shadows (very dark grey) 3 — Cloud shadows (dark brown) 4 — Vegetation (green) 5 — Not vegetated (dark yellow) 6 — Water (dark and bright) (blue) 7 — Unclassified (dark grey) 8 — Cloud medium probability (grey) 9 — Cloud high probability (white) 10 — Thin cirrus (very bright blue) 11 — Snow or ice (very bright pink)
Sampling	8 bit/sample
Resolution	60 m, 20 m

2.3 Atmospheric Correction

2.3.1 Input Data

L1C Image data as specified in Section 2.1.1, resampled to the requested resolution of 60, 20, 10 m.

Scene Classification as specified in Section 2.2 resampled to the requested resolution of 60, 20, 10 m.

2.3.2 GIPP

Figure 2 shows the overall GIPP of the Atmospheric Correction Module.

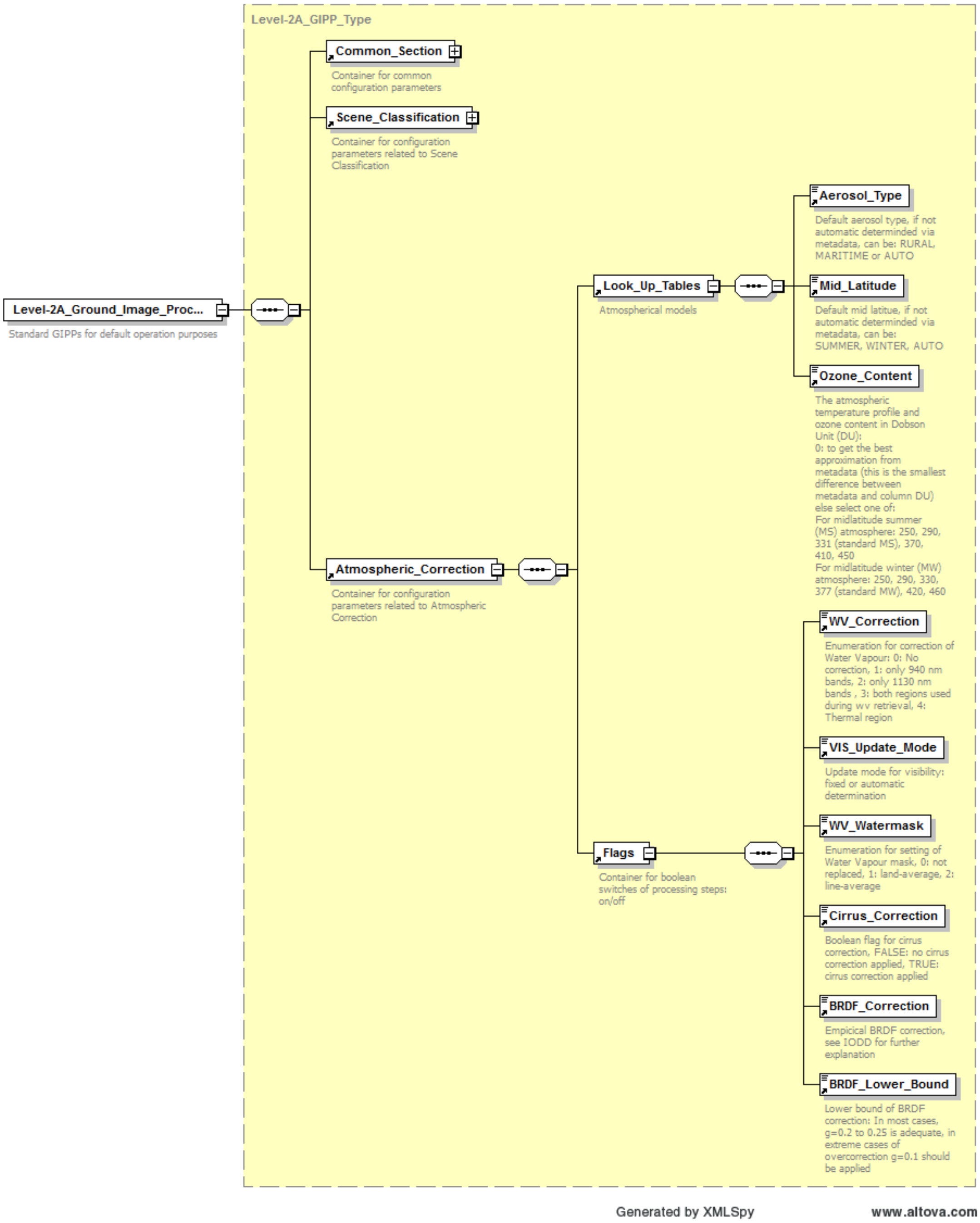


Figure 4 – GIPP for Atmospheric Correction Module

Table 9 – GIPP for selection of Look_Up_Tables

<table>
<tr><th>Field Name</th><th>Documentation</th><th>Type</th></tr>
<tr><td>Aerosol_Type</td><td>The aerosol type used for atmospheric correction: a selection of AUTO will perform an automated aerosol type determination for this parameter as described in the SUM for Section 2.2.2.2.2. Default is: RURAL.</td><td>Choice:
RURAL,
MARITIME,
AUTO</td></tr>
<tr><td>Mid_Latitude</td><td>The mid latitude used for atmospheric correction a selection of AUTO will perform an automated aerosol type determination for this parameter as described in the SUM for Section 2.2.2.2.2. default is: SUMMER</td><td>Choice:
SUMMER,
WINTER,
AUTO</td></tr>
<tr><td>Ozone_Content,
Summer</td><td>The atmospheric temperature profile and ozone content for Mid_Latitude Summer Atmosphere.
Default is: 0, which takes the best approximation from the ECMWFT metadata in the AUX_DATA folder of the input product. Otherwise the user can set the following numerical values:<table><tr><th>Dobson Units</th></tr><tr><td>250</td></tr><tr><td>290</td></tr><tr><td>331 (standard MS)</td></tr><tr><td>370</td></tr><tr><td>410</td></tr><tr><td>450</td></tr></table></td><td>Choice as given</td></tr>
</table>

Field Name	Documentation	Type
Ozone_Content, Winter	The atmospheric temperature profile and ozone content for Mid_Latitude Summer Atmosphere. Default is 0, which takes the best approximation from the ECMWFT metadata in the AUX_DATA folder of the input product. Otherwise the user can set the following numerical values: **Dobson Units**: 250; 290; 330; 377 (standard MW); 420; 460	Choice as given

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.

2.3.2.1 Expert Level

GIPP for the Scene Classification on Expert Level are separated from the standard User level and are collected in a different file, named L2A_CAL_AC_GIPP.xml. Whereas L2A_GIPP.xml is a pure user configuration file and thus is available for a standard user, the Expert level GIPPs are reserved for testing and calibration campaigns. Wrong calibrations might lead to heavy performance artefacts. The description of these parameters is thus postponed to Section 3.1 and standard users are warned to remain these calibration parameters untouched. For a full list of all GIPPs including their types, values and ranges, consult the embedded PDF in section 3.4.

2.3.3 Metadata

2.3.4 Auxiliary Data (Look Up Tables)

The algorithm for the atmospheric correction relies on a database of radiative transfer calculations using the DISORT 8-stream algorithm combined with the correlated k method. This has been converted to atmospheric LUTs based on the freely available LibRadtran library.

Table 10 – Parameter space for atmospheric correction

Parameter	Range	Increment / grid points
Solar zenith angle	0 -70°	10°
Sensor view angle	0 -10°	10°

Parameter	Range	Increment / grid points
Relative azimuth angle	0 -180°	30°(180°= backscatter)
Ground elevation	0 -2.5 km	0.5 km
Visibility	5 -120 km	5, 7, 10, 15, 23, 40, 80, 120 km
Water vapour, summer	0.4 -5.5 cm	0.4, 1.0, 2.0, 2.9, 4.0, 5.0 cm
Water vapour, winter	0.2 -1.5 cm	0.2, 0.4, 0.8, 1.1 cm

The baseline processing uses the mid-latitude summer (MS) atmospheric temperature / humidity profile with scaled water vapour columns of 0.4, 1.0, 2.0, 2.9, 4.0, and 5.0 cm (sea level geometry). A separate LUT file is used for each water vapour concentration. The baseline aerosol type is rural (continental). Calculations are performed for the ground elevations 0 – 2.5 km above sea level, in steps of 0.5 km. The default value of the ozone content is 331 DU (for sea level, decreasing with elevation). The water vapour dependent LUTs are used during the per-pixel water vapour retrieval for Sentinel-2 scenes.

The baseline LUTs are compiled for the rural aerosol and the mid-latitude summer (MS) atmosphere with its corresponding ozone column (331 DU for sea level). Other LUTs are selectable via configuration as is described for Section 2.3.6.2.

Water vapour columns are calculated using an equidistant 100 m grid.

<u>LUT file name conventions</u>: a name consists of 16 characters or numbers followed by the extension '.atm'. The first character defines the atmospheric temperature profile (h=summer, w=winter) and ozone content, followed by '99000' (indicating the symbolic satellite height of 99,000 m), followed by '_', then 'wvxy' where xy is the sea-level water vapour column, followed by '_' and a 4 letter aerosol identifier '_rura'.

Table 11 – LUT file naming conventions

Examples:	
h99000_wv29_rura.atm	MS atmosphere, water vapour=2.9 cm, rural, ozone=331 DU
w99000_wv11_rura.atm	MW atmosphere, water vapour=1.1 cm, rural, ozone=377 DU
Names for other aerosol types are coded with 4 letters, e.g.:	
h99000_wv29_mari.atm	MS, water vapour=2.9 cm, maritime, ozone=331 DU

Examples:	
h99000_wv29_urba.atm[1]	MS, water vapour=2.9 cm, urban, ozone=331 DU
h99000_wv29_dese.atm[1]	MS, water vapour=2.9 cm, desert, ozone=331 DU

The content are the following 6 radiative transfer functions for different atmospheric conditions, view angles 0° (nadir) and 10° off-nadir, and a range of solar geometries and relative azimuth angles.

Table 12 – Structure and format of the atmospheric LUT files

Column		Content
1.	Lp	path radiance
2.	Edf	diffuse flux at the sensor = (Tdir + Tdif)*Edif (where Edif is the diffuse solar flux at the ground)
3.	Edr	direct (beam) irradiance at the sensor= (Tdir + Tdif) * Tsun * E Where: Tsun is the sun-to-ground direct transmittance, E = extra-terrestrial solar irradiance
4.	Tdir	direct transmittance ground-to-sensor
5.	Tdif	diffuse transmittance ground-to-sensor
6.	s	spherical albedo of atmosphere

- The radiance, irradiance, and flux values are calculated for an earth-sun distance of 1 astronomical unit.
- Each LUT file stores the radiative transfer functions as float numbers in the binary platform independent XDR format.
- The Thuillier-2003 extraterrestrial solar irradiance spectrum is used for the calculation of the LUTs (see Ref. Thuillier et al. 2003). It has been provided by ESA expressed in $mW.m^{-2}.nm^{-1}$ resampled at 1 nm.

LUTs are calculated for:

- ne = 6 elevations (0-2.5 km, increment 0.5 km),
- nz = 8 solar zenith angles (0-70°, increment 10°),
- nv = 8 visibilities (5, 7, 10, 15, 23, 40, 80, 120 km), and

[1] Currently not compiled

- nb bands: nb=12 for the 60 m data; nb=12 for the 20 m data; nb=4 for the 10 m data of Sentinel-2.

The sequence of data is arranged in a file with 104 columns and nz*nv*nb lines:

Table 13 – Column structure of atmospheric LUT files

Column	Content
column 1	Solar zenith angle (first 0°, last 70°)
column 2	Visibility (first 5 km, last 120 km)
columns 3 – 8	Lp, Edf, Edr, Tdr, Tdf, s (nadir view), elevation=0 km
columns 9 – 19	Edf, Edr, Tdr, Tdf, Lp for 7 rel. azimuth angles 0(30)180°, at sensor view angle 10°, elevation = 0 km
columns 20 – 104	Columns 3 – 19 are repeated 5 times for the remaining elevations 0.5 to 2.5 km (increment 0.5 km)

Note: the spherical albedo s is the same for nadir and 10° off-nadir, therefore it is stored only once.

The contents of the file are written as a simple float binary array LUT=fltarr(2+17 * ne, nz, nv, nb) where the 17 radiative transfer functions are calculated for different parameter sets with ne (first=fastest loop = elevation), nz (second loop = solar zenith), nv (third loop = visibility) and nb (last loop = spectral band).

All Look Up Tables are located in two folders named lib_S2A and lib_S2B (for Sentinel 2A and/or Sentinel 2B satellite) in the sen2cor subdirectory and should never be changed or removed from a standard user, as they are essential for a proper atmospheric correction.

2.3.5 Output Data

Outputs are specified in the following subsections for the individual sub modules.

2.3.6 Aerosol Optical Thickness Retrieval

The aerosol optical thickness (τ) is defined as the integrated extinction coefficient over a vertical column of atmosphere of unit cross section. Extinction coefficient is the fractional depletion of radiance per unit path length (also called attenuation for radar frequencies). Example in formula:

$$I = I_0 (e^{-\tau})$$

2.3.6.1 Input Data

Band subset as specified in Section 2.1.1, resampled to corresponding resolution of 60, 20, 10 m.

Table 14 – Band subsets

Channels and Resolution	Purpose in L2A processing context
B2 (490nm): 10 m	Sensitive to Vegetation Aerosol Scattering
B4 (665nm): 10 m	Max Chlorophyll absorption
B12 (2190nm): 20 m	AOT determination

2.3.6.2 GIPP

Figure 2 shows the GIPP of the Atmospheric Correction Module for the selection of the Look Up Tables (LUTs).

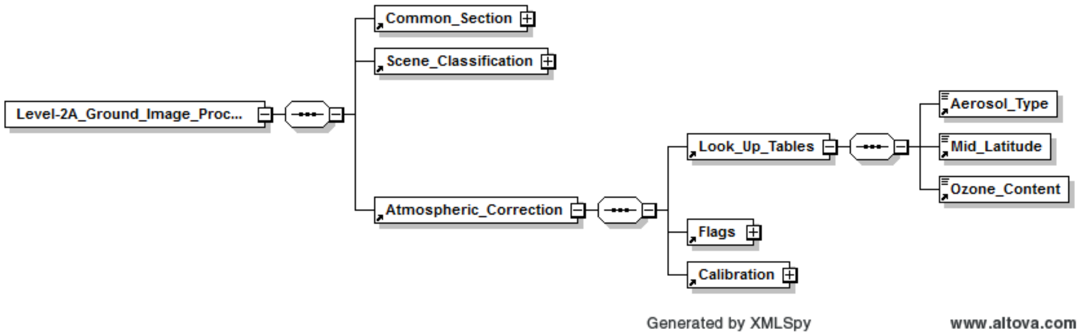


Figure 5– GIPP for selection of Look_Up_Tables

Table 15 – GIPP

Field Name	Documentation	Type
Visibility	visibility [km]	Floating point, 32 bit, default 40

2.3.6.3 Metadata

Metadata are specified in Section 0, Table 3.

2.3.6.4 Output Data

Table 16 – Aerosol Optical Thickness (AOT) map

Aerosol Optical Thickness (AOT) Map [Image Data]	
Unit	Unit less
Range	AOT = DN / 1000
Sampling	16 bit/pixel
Resolution	60 m, 20 m, 10 m (resampled from 20 m)

2.3.7 Water Vapour Retrieval

WV retrieval over land is performed with the Atmospheric Pre-corrected Differential Absorption algorithm (APDA) which is applied to the two Sentinel-2 bands B8A, and B9 (Fig. 4). Band 8A is the reference channel in an atmospheric window region. Band B9 is the measurement channel in the absorption region. The absorption depth is evaluated by calculating the radiance for an atmosphere with no WV, assuming that the surface reflectance for the measurement channel is the same as for the reference channel. The absorption depth is then a measure of the WV column content.

Typical ranges of water vapour columns are (sea-level-to space):

Table 17 – WVP columns

Conditions	WVP (cm)
tropical	3 - 5
midlatitude, summer	2 - 3
dry summer, spring, fall	1 – 1.5
dry desert or winter	0.3 – 0.8

2.3.7.1 Input Data

Band subsets are specified in Section 2.1.1, resampled to corresponding resolution of 60, 20 m.

Table 18 – Band subsets

Channels and Resolution	Purpose in L2A processing context
B8A (865nm): 20 m	Used for water vapour absorption (reference channel)
B9 (945nm): 60 m	Water Vapour absorption atmospheric correction (measurement channel)

2.3.7.2 GIPP

Table 19 – GIPP input fields

Field Name	Documentation	Type
WV_Correction	0: no water vapour correction 1: water vapour correction using band B8A	Enumerator 0,1 as stated, default: 1

Field Name	Documentation	Type
WV_Watermask	A choice to set the water vapour values for water pixels: 0 = not replaced, 1 = average water vapour value of land pixels is assigned to water pixels, ~~2 = line average of water vapour of land pixels is assigned to water pixels.~~ Only available with WV_Correction mode 1	Enumerator 1,2, as stated 1: default 2: for future use, currently unused
Smooth_WV_Map	smooth water vapour map [m]	Floating point, 32 bit, default: 100 m

2.3.7.3 Metadata

None

2.3.7.4 Output Data

Table 20 – Water Vapour Map

Water Vapour Map [Image Data]	
Unit	Dimensionless
Range	0.3 – 5.5 cm
Sampling	16 bit
Resolution	60 m, 20 m, 10 m

2.3.8 Cirrus Correction

2.3.8.1 Input Data

Table 21 – Band subset

Channels and Resolution	Purpose in L2A processing context
B10 (1375): 60 m	Detection of thin cirrus for atmospheric correction

2.3.8.2 GIPP

Table 22 – Inputs parameter cirrus correction

Field Name	Documentation	Type
Cirrus_Correction	Flag for cirrus removal TRUE: enabled FALSE: disabled	Restricted string, TRUE / FALSE as stated
WV_Threshold_Cirrus	Water Vapour threshold to switch cirrus algorithm off [%]	Floating point value, 32 bit, default: 0.25

2.3.8.3 Metadata

None

2.3.8.4 Output Data

Contribution of cirrus correction to BOA surface reflectance for individual channels as listed in Section 2.3.10 ff. The Cirrus band itself will be omitted in the Level 2A output, as it does not contain surface reflectance information. No direct user output.

2.3.9 Terrain Correction

2.3.9.1 Input Data

See metadata Section 2.3.9.3 below.

2.3.9.2 GIPP

Table 23 – GIPP terrain correction

Field Name	Documentation	Type
DEM_Directory	Directory where DEM will be expected (located under $S2L2APPHOME). If set to 'false', no terrain correction will be performed. Example: 'dem/srtm'	Formatted string
DEM_Reference	Example: http://data_public:GDdci@data.cgiar-csi.org/srtm/tiles/GeoTIFF/	Formatted string
DEM_Terrain_Correction	Boolean Flag for using DEM for terrain correction. Otherwise only used for scene classification and AOT	Formatted string

Field Name	Documentation	Type
Altitude	Assumed altitude if no DEM is present [km]	Floating point value, 32 bit, default: 0.10, equals 100 m

Field Name	Documentation	Type
BRDF_Correction	Empirical BRDF correction with factor (G) according to following equation: $G = \{ \cos(\beta_i) / \cos(\beta_T) \}^b \geq g$ (eq. 1) where: β_i: local solar zenith angle (from metadata, Section 1.1.3). β_T: threshold for surface reflectance (determined programmatically). b: exponent, set via options below. g: Lower boundary of BRDF correction factor, recommended between 0.2 and 0.25 (see next parameter, below). Options to be selected (Exponent b): 0: no empirical BRDF correction (or flat terrain) 1: correction with cosine of local solar zenith angle (eq. 1 with b=1) 2: correction with sqrt(cos) of local solar zenith angle (eq. 1 with b=1/2) 11: correction with cosine of local solar zenith angle (eq. 1 with b=1), for soil/sand. Vegetation: (eq. 1) but with exponent b=1/3 (λ< 720 nm), and b=3/4 (λ > 720 nm), (”weak” correction). 12: correction with cosine of local solar zenith angle (eq. 1 with b=1), for soil/sand. Vegetation: (eq. 1) but with exponent b=1.0 (λ < 720 nm), and b=3/4 (λ > 720 nm), (”strong” correction), 21: correction with sqrt(cos) of local solar zenith angle (eq. 1 with b=1/2), for soil/sand. Vegetation: (eq. 1) but with exponent b=1/3 (λ < 720 nm), and b=3/4 (λ > 720 nm), (”weak” correction). **This is the recommended standard yielding good results in most cases.** 22: correction with sqrt(cos) of local solar zenith angle (eq. 1 with b=1/2), for soil/sand. Vegetation: (eq. 1) but with exponent b=1.0 (λ < 720 nm), and b=3/4 (λ > 720 nm, (”strong” correction).	Enumerator 0, 1, 2, 11, 12, 21, 22

Field Name	Documentation	Type
BRDF_Lower_Bound	Lower boundary of BRDF correction factor, should be between 0.2 and 0.25.	Float, default 0.22

2.3.9.3 Metadata

- DEM (as specified in the GIPP, will be internally prepared and adapted to geo-positional coordinates obtained from the JPEG-2000 image headers)
- Terrain Shadow Map (calculated internally via GDAL)
- Slope Map (calculated internally via GDAL)
- Aspect Map (calculated internally via GDAL)

2.3.9.4 Output Data

Corrections of BOA surface reflectance retrieval for bands B01 – B12, except B10) as listed in Section 2.3.10. No separate user output.

2.3.10 Surface Reflectance

2.3.10.1 Input Data

60, 20 m Resolution

- Full set of Bands as specified in Section 2.1.1, Table 1, (except Band 8) resampled to corresponding resolution;
- Aerosol Map as specified in Table 16;
- Water Vapour Map as specified in Table 20;
- (Optional) Cirrus correction as specified in Section 2.3.8.4;
- (Optional) Terrain correction as specified in Section 2.3.9.4.

10 m Resolution

- Bands 2,3,4,8 as specified in Section 2.1.1, Table 1, no resampling;
- Resampled Aerosol Map as specified in Table 16;
- Water Vapour Map as specified in Table 20;
- (Optional) Terrain correction as specified in Section 2.3.9.4

2.3.10.2 GIPP

Table 24 – GIPP surface reflectance

Field Name	Documentation	Type
Adj_Km	Range of adjacency effect (reflected radiation from neighbourhood) in [km]	Floating point, 32 bit, Default: 1.0

2.3.10.3 Metadata

None

2.3.10.4 Output Data

Table 25 – Outputs surface reflectance

Name	Level-2A
Product	L2A, BOA Reflectance
Coverage	Regional
Packaging	Tiles (same area coverage as Level 1C input data)
Geo-location accuracy	Identical to the level 1C geo-location performance.
Frequency	Variable upon Level 1C products availability.

<table>
<tr><th>Name</th><th>Level-2A</th></tr>
<tr><td>Format</td><td>OpenJPEG 2.1.2 details @60 m processing:

<pre>Codestream, export Band 1, res 60m:
SOC marker segment @ (1866, 0)
SIZ marker segment @ (1868, 41)
Profile: no profile
Reference Grid Height, Width: (1830 x 1830)
Vertical, Horizontal Reference Grid Offset: (0 x 0)
Reference Tile Height, Width: (192 x 192)
Vertical, Horizontal Reference Tile Offset: (0 x 0)
Bitdepth: (16,)
Signed: (False,)
Vertical, Horizontal Subsampling: ((1, 1),)
COD marker segment @ (1911, 18)
Coding style:
Entropy coder, with partitions
SOP marker segments: False
EPH marker segments: False
Coding style parameters:
Progression order: LRCP
Number of layers: 1
Multiple component transformation usage: no transform specified
Number of resolutions: 6
Code block height, width: (4 x 4)
Wavelet transform: 5-3 reversible
Precinct size: ((64, 64), (64, 64), (64, 64), (64, 64), (64, 64), (64, 64))
Code block context:
Selective arithmetic coding bypass: False
Reset context probabilities on coding pass boundaries: False
Termination on each coding pass: False
Vertically stripe causal context: False
Predictable termination: False
Segmentation symbols: False
QCD marker segment @ (1931, 19)
Quantization style: no quantization, 2 guard bits
Step size: [(0, 16), (0, 17), (0, 17), (0, 18), (0, 17), (0, 17), (0, 18), (0,
17), (0, 17), (0, 18), (0, 17), (0, 17), (0, 18), (0, 17), (0, 17), (0, 18)]
CME marker segment @ (1952, 37)</pre></td></tr>
<tr><td>Unit</td><td>Dimensionless, Unsigned Integer</td></tr>
<tr><td>Calibration and Range</td><td>1 / 10.000: i.e.: Digital Numbers 0 : 10.000, representing radiometric reflectance values from 0.0 to 1.0</td></tr>
<tr><td>Sampling</td><td>16 bits / pixel</td></tr>
<tr><th>Input resolution</th><th>Generated output resolution</th></tr>
<tr><td>B1 (443nm): 60 m</td><td>60 m</td></tr>
<tr><td>B2 (490nm): 10 m</td><td>60 m, 20 m, 10 m</td></tr>
</table>

Name	Level-2A
B3 (560nm): 10 m	60 m, 20 m, 10 m
B4 (665nm): 10 m	60 m, 20 m, 10 m
B5 (705nm): 20 m	60 m, 20 m
B6 (740nm): 20 m	60 m, 20 m
B7 (783nm): 20 m	60 m, 20 m
B8 (842nm): 10 m	10 m
B8a (865nm): 20 m	60 m, 20 m
B9 (945nm): 60 m	60 m
B10 (1375): 60 m	No output generated as it does not contain surface information
B11 (1610nm): 20 m	60 m, 20 m
B12 (2190nm): 20 m	60 m, 20 m

2.4 Product Generation

2.4.1 Input Data

All outputs from previous sections.

2.4.2 Output Data

The generated output is dependent on the command line input as shown below. The output products itself are described and specified in detail in [S2-PDGS-MPC-L2A-PFS] and thus not repeated here.

2.4.2.1 Datastrip Generation

Command Line Parameter:

```
L2A_Process --mode=generate_datastrip --datastrip=L1C_DATASTRIP
        --output_dir=L2A_OUTPUT_DIR --work_dir=WORK_DIR --processing_centre=PROCESSING_CENTRE
        --archiving_centre=ARCHIVING_CENTRE --GIP_L2A_PB=GIP_L2A_PB (optional)
        --resolution=RESOLUTION (optional)
```

Generates a datastrip with optional processing baseline settings, which can be used as input for the next step of processing a single tile.

Input product should be in SAFE standard format. Output product will have the datastrip directory in SAFE standard format as well, all other components like metadata and reports will be generated in SAFE compact format.

2.4.2.2 Tile Generation

Command Line Parameter:

```
L2A_Process --mode=process_tile --datastrip=L2A_DATASTRIP --tile=L1C_TILE
        --output_dir=L2A_OUTPUT_DIR --work_dir=WORK_DIR --GIP_L2A_PB=GIP_L2A_PB (optional)
        --resolution=RESOLUTION (optional) --img_database_dir=IMG_DATABASE_DIR (optional)
        --res_database_dir=RES_DATABASE_DIR (optional)
```

Processes a tile with optional database locations and optional processing baseline settings, using a generated L2A datastrip as input. Database directories have been split into two different entities, one for the L1C image inputs, which will be kept in read only mode and a second database for the resampled auxiliary and intermediate products, which always will be overwritten and removed during the successive processing steps.

Input product should be in SAFE standard format. Output product will have the tile directory in SAFE standard format as well, all other components like metadata images and reports will be generated in SAFE compact format.

2.4.2.3 EUP Generation (Toolbox Mode)

Command Line Parameter:

```
L2A_Process input
usage: L2A_Process L1C_USER_PRODUCT --GIP_L2A_PB=GIP_L2A_PB (optional)
        --resolution=RESOLUTION (optional)
```

Processes an End User Product with optional processing baseline settings, using an L1C End User product of PSD Version 14.3 as input.

Input product should be V.14.3 SAFE compact format. Output product will also be generated in SAFE compact format. Older products below PSD 14.3 will no longer be supported.

3. GIPP Additional Settings

3.1 Expert Parameters for Scene Classification

The default expert parameters for the Scene Classification are located in a file named L2A_CAL_SC_GIPP.xml, located in the cfg folder of the sen2cor subdirectory within the Sen2Cor package. They can be overwritten with an external configuration referred to via command line (see section 2.1.6).

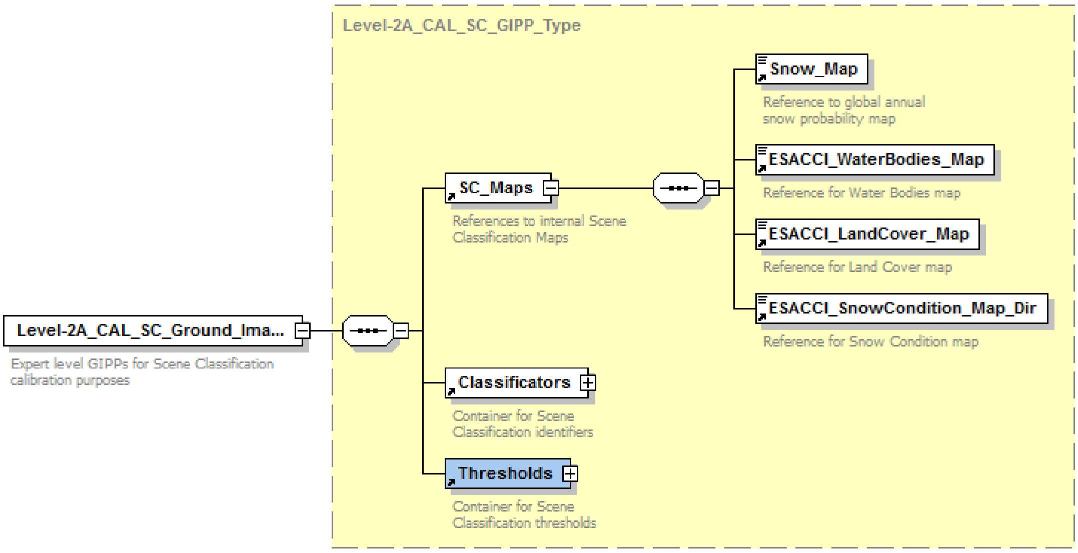


Figure 6 – Processing Baseline GIPP

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.

3.2 Expert Parameters for Atmospheric Correction

The default expert parameters for the Atmospheric Correction are located in a file named L2A_CAL_AC_GIPP.xml, located in the cfg folder of the sen2cor subdirectory within the Sen2Cor package. They can be overwritten with an external configuration referred to via command line (see section 2.1.6).

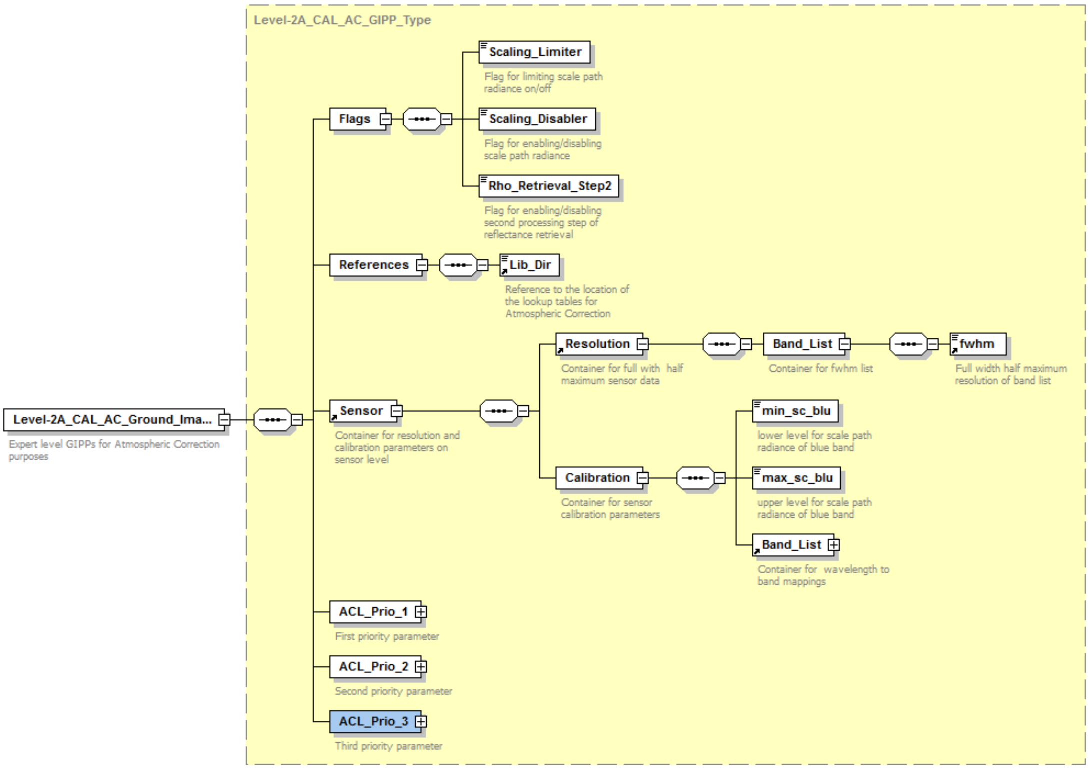


Figure 7 – Processing Baseline GIPP

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.

3.3 Processing Baseline Parameters

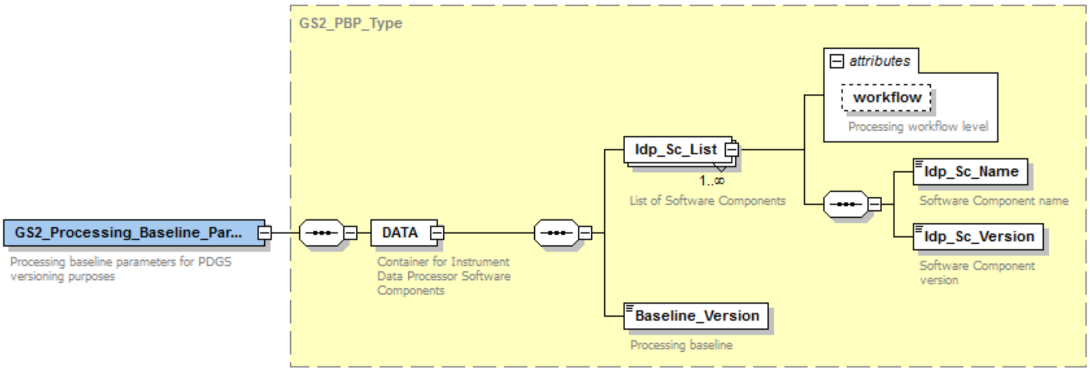


Figure 8 – Processing Baseline GIPP

Table 26 – Processing Baseline GIPP

Field Name / Attribute	Documentation	Type
DATA	Container for Instrument Data Processor Software Components	Complex
IDp_Sc_List	List of Software Components	Complex
workflow	Processing workflow level	String
IDp_Sc_Name	Software Component name	String
IDp_Sc_Version	Software Component version	String
Baseline_Version	Processing baseline	Double

Adding an optional xml input in the format of a processing baseline allows overwriting the corresponding fields in the metadata and filenames.

For a full list of all types, parameters and default values, consult the embedded PDF in section 3.4.

3.4 S2-PDGS-MPC-L2A-IODD-V2.8.0-GIPP-Scheme

The full reference of all GIPP is contained in the embedded PDF document:

S2-PDGS-MPC-L2A-IODD-V2.8.0-GIPP-Sc