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Title : **Sentinel-2 MSI – Level-2A Input Output Data Definition**

Abstract : This Document lists the Input Output Data Definitions of the Sen2Core application. Sen2Core is a prototype processor for Sentinel-2 Level 2A product processing and formatting. The processor is developed for and with ESA and performs the tasks of Atmospheric Correction and Scene Classification of Level 1C input data. Level 2A outputs are: Bottom-Of-Atmosphere (BOA) corrected reflectance images, Aerosol Optical Thickness-, Water Vapour-, Scene Classification maps and Quality indicators, including cloud and snow probabilities. The Level 2A Product Formatting performed by the processor follows the specification of the Level 1C User Product.

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TABLE OF CONTENTS

1. INTRODUCTION 9
1.1 Purpose and Scope 9
1.2 Document Overview 9
1.3 Documentation and Definitions 9
1.3.1 Normative Reference Documents 9
1.3.2 Informative Reference Documents 9

2. LEVEL-2A PRODUCTS OVERVIEW 11
2.1 Processing Workflow 11
2.2 Common Data 11
2.2.1 Input Data 11
2.2.2 Ground Image Processing Parameter 12
2.2.3 Metadata 13
2.2.4 Output Data 14
2.3 Scene Classification 14
2.3.1 Processing Workflow 14
2.3.2 Input Data 15
2.3.3 GIPP 15
2.3.4 Metadata 17
2.3.5 Output Data 17
2.4 Atmospheric Correction 20
2.4.1 Processing Workflow 20
2.4.2 Input Data 20
2.4.3 GIPP 20
2.4.4 Metadata 21
2.4.5 Auxiliary Data (Look Up Tables) 21
2.4.6 Output Data 24
2.4.7 Aerosol Optical Thickness Retrieval 24
2.4.7.1 Input Data 24
2.4.7.2 GIPP 24
2.4.7.3 Metadata 25
2.4.7.4 Output Data 25
2.4.8 Water Vapour Retrieval 25
2.4.8.1 Input Data 25
2.4.8.2 GIPP 26
2.4.8.3 Metadata 26
2.4.8.4 Output Data 26
2.4.9 Cirrus Correction 26
2.4.9.1 Input Data 26
2.4.9.2 GIPP 27
2.4.9.3 Metadata 27
2.4.9.4 Output Data 27
2.4.10 Terrain Correction 27
2.4.10.1 Input Data 27
2.4.10.2 GIPP 27
2.4.10.3 Metadata 28
2.4.10.4 Output Data 29
2.4.11 Surface Reflectance 29
2.4.11.1 Input Data 29
2.4.11.2 GIPP 29
2.4.11.3 Metadata 29
2.4.11.4 Output Data 30
2.5 Post Processing 31
2.5.1 Input Data 31
2.5.2 Output Data 31

3. APPENDIX: EXAMPLE OF GIPP FILE 32

List OF Figures

Figure 2-1 – Processing Flow, Overview 11

Figure 2-2 – Scene Classification, Processing Flow 15

Figure 2-3 – Atmospheric Correction, Processing Flow 20

Figure 2-4 – Level 2A product, physical format 31

LIST OF TABLES

Table 1 – L1C Image data specification 11
Table 2 – Common GIPP 13
Table 3 – Metadata input fields (see L2A-PFS for details) 13
Table 4 – Classification map 15
Table 5 – GIPP input fields 16
Table 6 – Snow Climatology map 17
Table 8 – Cloud Probability map 17
Table 9 – Snow Probability map 18
Table 7 – Scene Classification 18
Table 10 – GIPP input fields 20
Table 11 – Parameter space for atmospheric correction 21
Table 12 – LUT file naming conventions 22
Table 13 – First character ID's for Median Summer with different ozone concentrations 22
Table 14 – First character ID's for MW with different ozone concentrations 22
Table 15 – Structure and format of the atmospheric LUT files 23
Table 16 – Column structure of atmospheric LUT files 23
Table 17 – Band subsets 24
Table 18 – GIPP input fields 24
Table 19 – Aerosol Optical Thickness (AOT) map 25
Table 20 – Band subsets 25
Table 21 – GIPP input fields 26
Table 22 – Water Vapour Map 26
Table 23 – Band subset 26
Table 24 – Inputs parameter cirrus correction 27
Table 25 – GIPP terrain correction 27
Table 26 – GIPP surface reflectance 29
Table 27 – Outputs surface reflectance 30

AMENDMENT POLICY

This document shall be amended by releasing a new edition of the document in its entirety. The Amendment Record Sheet below records the history and issue status of this document.

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DOCUMENT CHANGE RECORD

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1. INTRODUCTION

1.1 Purpose and Scope

This Document lists the Input Output Data Definitions of the Sen2Core application. Sen2Core is a prototype processor for Sentinel-2 Level 2A product processing and formatting. The processor is developed for and with ESA and performs the tasks of Atmospheric Correction and Scene Classification of Level 1C input data. Level 2A outputs are: Bottom-Of-Atmosphere (BOA) corrected reflectance images, Aerosol Optical Thickness-, Water Vapour-, Scene Classification maps and Quality indicators, including cloud and snow probabilities

1.2 Document Overview

This IODD will list 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 into the following four criteria:

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

1.3 Documentation and Definitions

The reference list of all project related documents with their full version numbers and issue dates is given in:

[L2A-GLODEF] S2PAD Project Glossary, S2PAD-VEGA-GLO-0001, version 3.3, 31.03.2014

1.3.1 Normative Reference Documents

[L2A-PFS] Sentinel-2 MSI – Product Format Specification

[L2A-PDD] Sentinel-2 MSI – Level-2A Product Definition Document

1.3.2 Informative Reference Documents

[L2A-ATBD] Sentinel-2 MSI – Level 2A Products, Algorithm Theoretical Basis Document

[L2A-DPM] Sentinel-2 MSI – Level 2A Detailed Processing Model

[L2A-SUM] Sentinel-2 MSI – Level 2A Software Installation and User Manual

[PDD] GMES Space Component – Sentinel-2 Payload Data Ground Segment (PDGS), Product Definition Document, GMES-GSEC-EOPG-TN-09-0029, Issue 2 Revision 3, 30.03.2012

[PSD] Sentinel-2 Product Specification Documentation - S2-PDGS-TAS-DI-PSD – version 10.0, 12.07.2013

2. LEVEL-2A PRODUCTS OVERVIEW

2.1 Processing Workflow

Figure 2-1 below shows the main processing workflow. After reading and processing the input parameter and data the main processing module triggers the creation of an internal temporary database, which is then used by the SC and the AC module to retrieve and to store the data and intermediate products.

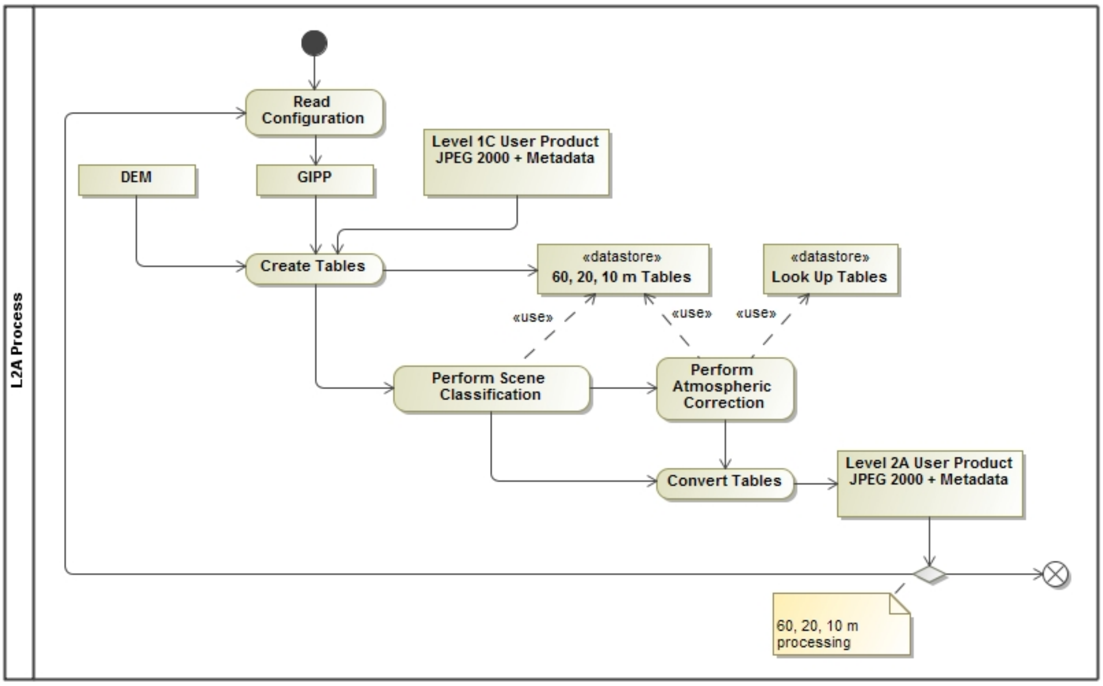

Figure 2-1 – Processing Flow, Overview

2.2 Common Data

2.2.1 Input Data

Table 1 – L1C Image data specification

Name	Level-1C
Parent Product	L1C, TOA Reflectance
Coverage	Regional
Packaging	Tiles (same size and 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.
Format	JPEG 2000

Name	**Level-1C**
Unit	Dimensionless, Unsigned Integer
Calibration and Range	1 / 4000: i.e.: Digital Numbers 0 : 4000, representing radiometric reflectance values from 0.0 to 1.0
Sampling	12 bits/pixel
Channels and Resolution	**Purpose in L2A processing context**
B1 (443nm): 60m	Atmospheric Correction
B2 (490nm): 10m	Sensitive to Vegetation Aerosol Scattering
B3 (560nm): 10m	Green peak, sensitive to total chlorophyll in vegetation
B4 (665nm): 10m	Max Chlorophyll absorption
B5 (705nm): 20m	Not used in L2A context
B6 (740nm): 20m	Not used in L2A context
B7 (783nm): 20m	Not used in L2A context
B8 (842nm): 10m	Leaf Area Index (LAI)
B8a (865nm): 20m	Used for water vapour absorption reference
B9 (945nm): 60m	Water Vapour absorption atmospheric correction
B10 (1375): 60m	Detection of thin cirrus for atmospheric correction
B11 (1610nm): 20m	Soils detection
B12 (2190nm): 20m	AOT determination

2.2.2 Ground Image Processing Parameter

Ground Image Processing Parameter (GIPP) are configured in an XML file named L2A_GIPP.xml, located in the <cfg> subdirectory of the processor (see example in the appendix), where they can be configured by the user. For each processed Level 2A tile the GIPP xml file will be renamed to S2A_USER_GIP_L2A_TL_<TILE_ID> (see section A.2.3 of [L2A_PFS]) and subsequently copied into the AUX_DATA subfolder of the corresponding granule. The GIPP are listed in their current context.

Table 2 thus lists only the common GIPP. Specific GIPP are located in the corresponding subsections for each sub processes separately.

Table 2 – Common GIPP

Field Name	Documentation	Type
Trace_Level	Verbosity level of the tracing output, located in the GRANULE/<GRANULE>/QI_DATA folder.	Enumerator: NOTSET, DEBUG, INFO, WARNING, ERROR, CRITICAL
DN_Scale	Scale Factor for Digital Numbers: default range 0 : 4000, representing radiometric reflectance values from 0.0 to 1.0	Unsigned integer
Sensor Calibration[1]		
wavelength	List of wavelength (per band)	Floating point array 32 bit
fwhm	List of spectral resolutions (full width at half maximum, per band)	Floating point array 32 bit
e0	List of extra-terrestrial solar irradiance (per band)	Floating point array 32 bit
c0	List of radiometric calibration constants (offset, per band)	Floating point array 32 bit
c1	List of radiometric calibration constants (slope, per band)	Floating point array 32 bit

2.2.3 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

[1] *This table is preliminary and will be replaced by the corresponding sensor values from the Level-1C metadata in a later issue.*

Field Name	Documentation	Type
Azimuth	Grids for Azimuth Viewing Incidence Angle values (0 – 360°)	Floating point array 32 bit
DEM	SRTM data	String
ECMWF	ECMWF for L1C (ozone, currently unused)	String

2.2.4 Output Data

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

2.3 Scene Classification

2.3.1 Processing Workflow

Figure 2-1 below shows the main processing workflow for the Scene Classification. The SC algorithm allows to detect clouds, snow and cloud shadows and to generate a classification map, which consists of 4 different classes for clouds (including cirrus), together with six different classifications for shadows, cloud shadows, vegetation, soils / deserts, water and snow. The algorithm is based on a series of threshold tests that use as input top-of-atmosphere reflectance from the Sentinel-2 spectral bands. In addition, thresholds are applied on band ratios and indexes like the Normalized Difference Vegetation - and Snow Index (NDVI, NDSI [3]). For each of these thresholds tests, a level of confidence is associated. At the end of the processing chain a probabilistic cloud mask quality map and a snow mask quality map is produced. The algorithm uses the reflective properties of scene features to establish the presence or absence of clouds in a scene. Cloud screening is applied to the data in order to retrieve accurate atmospheric and surface parameters, either as input for the further processing steps below or for being valuable input for processing steps of higher levels

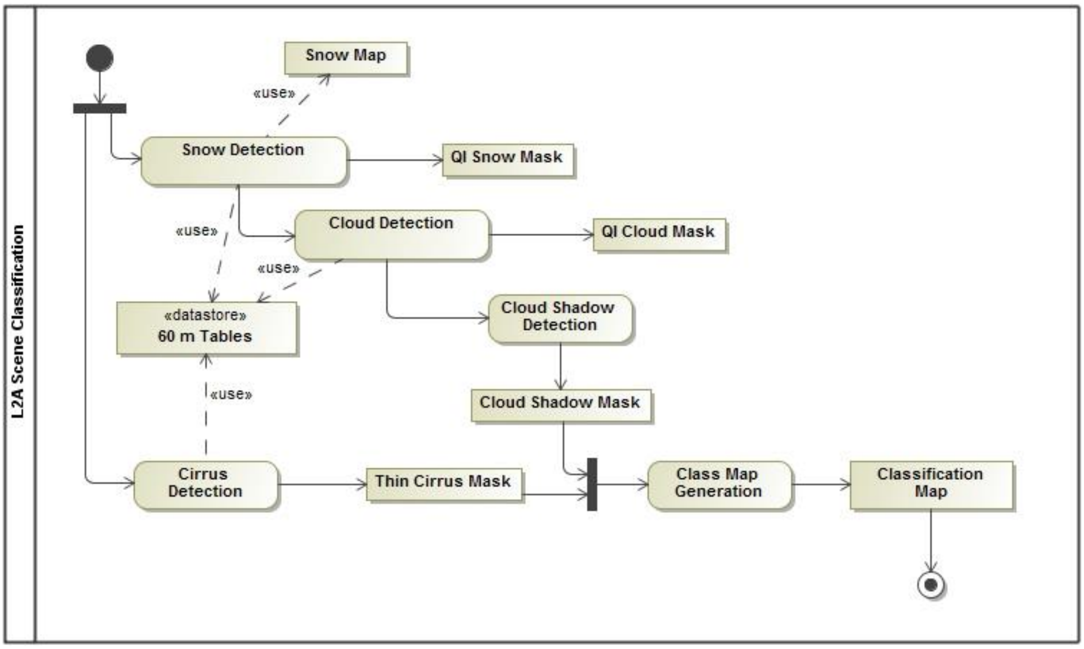

Figure 2-2 – Scene Classification, Processing Flow

2.3.2 Input Data

L1C Image data as specified in section 2.2.1, resampled to the requested resolution of 60, 20, 10m.

2.3.3 GIPP

Table 4 – Classification map

Enumeration	Classification
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	Bare soils / deserts (dark yellow)
6	Water (dark and bright) (blue)
7	Cloud low probability (dark grey)
8	Cloud medium probability (grey)
9	Cloud high probability (white)
10	Thin cirrus (very bright blue)

Enumeration	Classification
11	Snow or ice (very bright pink)

Table 5 – GIPP input fields

Thresholds (see corresponding paragraphs of L2A_ATBD for details)		
Type	Unsigned Integer	
Parameter	Default Value (dimensionless)	Context (ATBD section reference)
Median_Filter	3	Classification map generation, 3.5,
Type	Floating Point 32 bit	
Parameter	Default Value (dimensionless)	Context (ATBD section reference)
T1_B04	0.07	Step 1, 3.2.1.1
T2_B04	0.25	"
T1_NDSI_CLD	-0.24	Step 1b, 3.2.2
T2_NDSI_CLD	-0.16	"
T1_NDSI_SNW	0.20	Snow Filter 1, 3.2.3.2
T2_NDSI_SNW	0.42	"
T1_B08	0.15	Snow Filter 2, 3.2.3.3
T2_B08	0.35	"
T1_B02	0.18	Snow Filter 3, 3.2.3.4
T2_B02	0.22	"
T1_R_B2B4	0.85	Snow Filter 4, 3.2.3.5
T2_R_B2B4	0.95	"
T1_NDVI	0.36	Step 3, 3.2.4
T2_NDVI	0.40	"
T1_R_B8B3	1.50	Step 4, 3.2.5
T2_R_B8B3	2.50	"
T11_R_B2B11	0.55	Step 5, 3.2.6.1
T12_R_B2B11	0.80	"
T11_B02	-0.40	"
T12_B02	0.46	"
T21_R_B2B11	2.10	Step 5, 3.2.6.2
T22_R_B2B11	4.00	"

Thresholds (see corresponding paragraphs of L2A_ATBD for details)		
T21_B12	0.1	"
T22_B12	0.09	"
T1_R_B8B11	0.90	Step 6, 3.2.7
T2_R_B8B11	1.10	"
T1_B10	0.012	Cirrus detection, 3.3.1
T2_B10	0.035	"
T_CLOUD_LP	0.0	Low probability clouds, 3.3.2
T_CLOUD_MP	0.35	Medium probability clouds, 3.3.2
T_CLOUD_HP	0.65	Hi probability clouds, 3.3.2
RV_B2	6.96000	Radiometric inputs, 3.4.1
RV_B3	5.26667	"
RV_B4	5.37708	"
RV_B8	7.52000	"
RV_B11	5.45000	"
RV_B12	2.55000	"
T_SDW	0.50	Shadow threshold, 3.4.4

2.3.4 Metadata

Table 6 – Snow Climatology map

Field Name	**Documentation**	**Type**
S2_L2A-SNOW_CLIMATOLOGY_MAP	GlobalSnowMap.tiff. Boolean map for the occurrence of Snow during the last 10 years. Located in the <S2L2APP>/lib/20_60 folder Only for internal usage, no user output	Geo Tiff bitmap, 7200 x 3600 pixel, 255 byte. Corresponds to latitude / longitude values between +- 180, resp. +/- 90 degrees. Resolution: 20 pixel / degree.

Additional metadata are specified in Section 2.2.3, Table 3.

2.3.5 Output Data

Table 7 – Cloud Probability map

Cloud Probability [QI Data]	
Unit	percentage

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

Table 8 – Snow Probability map

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

Table 9 – 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 – Bare soils / deserts (dark yellow) 6 – Water (dark and bright) (blue) 7 – Cloud low probability (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) Note: Scene Classification pixels are set to 1 (Saturated or defective pixel) if at least one band involved in the L2A_SC is affected by Level-1C quality masks. See [S2-L2A-PDD, section 3.4.3] for details.
Sampling	8 bit/sample
Resolution	60m, 20m

2.4 Atmospheric Correction

2.4.1 Processing Workflow

Figure 2-3 below shows the main processing workflow for the Atmospheric Correction. The AC processing consists of a set of four different subtasks, (Aerosol Optical Thickness (AOT), Water Vapour (WV) and terrain retrieval (optional with terrain, BRDF and cirrus correction, having three different user products as output: AOT and WV tables on pixel level and the BOA corrected reflectance images for all bands measured.

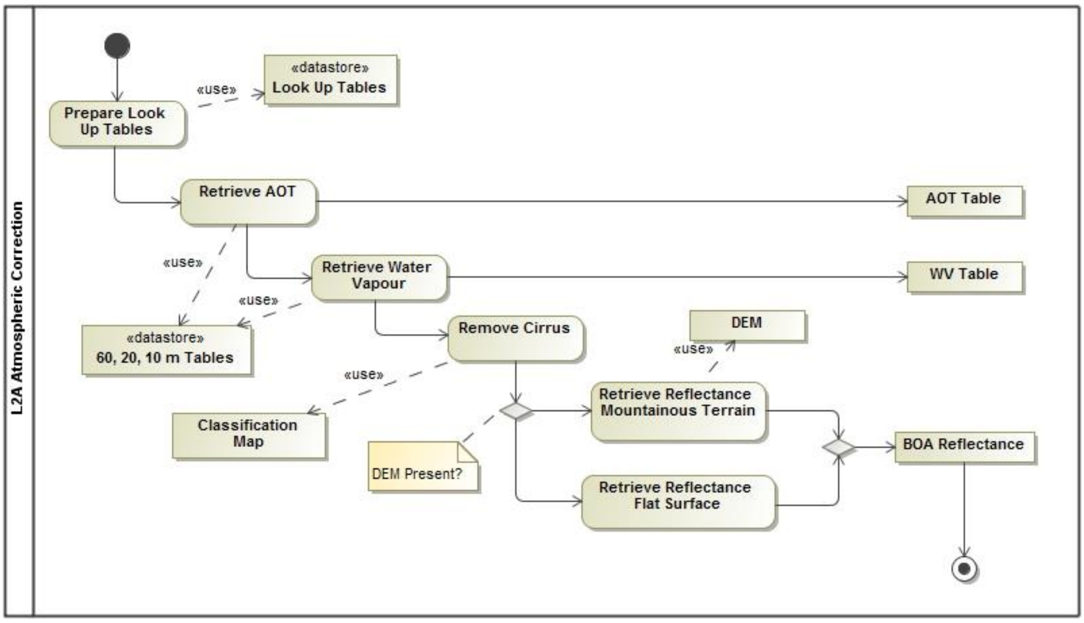

Figure 2-3 – Atmospheric Correction, Processing Flow

2.4.2 Input Data

2.4.3 GIPP

Table 10 – GIPP input fields

Field Name	Documentation	Type
Lib_Dir	Location for the look up tables, default is $S2L2APPHOME/lib/<resolution>	Formatted string
Atm_Data_Filename	A choice to set the water vapour values for water pixels: 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.	Formatted string

2.4.4 Metadata

2.4.5 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 11 – Parameter space for atmospheric correction

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

Water vapour columns are calculated using an equidistant 100 m grid, and results are stored in the subroutines “load_wv_tables_summer” and “load_wv_tables_winter”.

Aerosol type: baseline is rural, others are optional[2] (e.g. maritime, desert, urban).

LUT file name conventions: 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’.

[2] *Currently not compiled.*

Table 12 – 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
h99000_wv29_urba.atm	MS, water vapour=2.9 cm, urban, ozone=331 DU
h99000_wv29_dese.atm	MS, water vapour=2.9 cm, desert, ozone=331 DU

Table 13 – First character ID's for Median Summer with different ozone concentrations

ID	Dobson Units
'f'	250 DU
'g'	290 DU
'h'	331 DU (standard MS)
'i'	370 DU
'j'	410 DU
'k'	450 DU

The value closest to ECMWF[3] or GOME data is selected.

Table 14 – First character ID's for MW with different ozone concentrations

ID	Dobson Units
't'	250 DU
'u'	290 DU
'v'	330 DU
'i'	377 DU (standard MW)
'j'	420 DU
'k'	460 DU

---

[3] *ECMWF data are distributed in Kg/m2 and have to be converted to DU before used for selection.*

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 15 – 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.
- Extraterrestrial solar irradiance spectrum is: Thuillier spectrum [RD.09]: http://media.libsyn.com/media/npl1/Solar_irradiance_Thuillier_2002.xls

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
- 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 16 – 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

Column	Content
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).

2.4.6 Output Data

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

2.4.7 Aerosol Optical Thickness Retrieval

2.4.7.1 Input Data

Band subset as specified in Section 13 Table 1, resampled to corresponding resolution of 60, 20, 10m.

Table 17 – Band subsets

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

2.4.7.2 GIPP

Table 18 – GIPP input fields

Field Name	Documentation	Type
Visibility	visibility [km]	Floating point, 32 bit
NP_Ref	0 : constant visibility 1 : variable visibility, based on dark reference areas in the scene	Enumerator 0,1 as stated

2.4.7.3 Metadata

Metadata are specified in Section 2.2.3, Table 3.

2.4.7.4 Output Data

Table 19 – Aerosol Optical Thickness (AOT) map

Aerosol Optical Thickness (AOT) Map [Image Data]	
Unit	Dimensionless
Range	0 – 1
Sampling	16 bit
Resolution	60m, 20m

2.4.8 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.

2.4.8.1 Input Data

Band subsets are specified in Section 13 Table 1, resampled to corresponding resolution of 60, 20m.

Table 20 – Band subsets

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

2.4.8.2 GIPP

Table 21 – 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
WV_Watermask	A choice to set the water vapour values for water pixels: 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, default: 1
Smooth_WV_Map	smooth water vapour map [m]	Floating point, 32 bit, default: 100 m

2.4.8.3 Metadata

None

2.4.8.4 Output Data

Table 22 – Water Vapour Map

Water Vapour Map [Image Data]	
Unit	Dimensionless
Range	0.4 – 5.5 cm
Sampling	16 bit
Resolution	60m, 20m

2.4.9 Cirrus Correction

2.4.9.1 Input Data

Table 23 – Band subset

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

2.4.9.2 GIPP

Table 24 – Inputs parameter cirrus correction

Field Name	Documentation	Type
Cirrus_Correction	Flag for cirrus removal 0: disabled 1: enabled	Enumerator 0,1 as stated
WV_Threshold_Cirrus	Water Vapour threshold to switch cirrus algorithm off [%]	Floating point value, 32 bit, default: 0.25

2.4.9.3 Metadata

None

2.4.9.4 Output Data

Contribution of cirrus correction to BOA surface reflectance for individual channels as listed in section 2.4.11 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.

2.4.10 Terrain Correction

2.4.10.1 Input Data

See metadata section 2.4.10.3 below.

2.4.10.2 GIPP

Table 25 – 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_Unit	0: m, 1: dm, 2: cm	Enumerator, 0 – 2. Default 0 [m]

Field Name	Documentation	Type
Altitude	Assumed altitude if no DEM is present [km]	Floating point value, 32 bit, default: 0.10, equals 100 m
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 0). 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: 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
BRDF_Lower_Bound	Lower boundary of BRDF correction factor, should be between 0.2 and 0.25.	Float

2.4.10.3 Metadata

- DEM (as specified in the GIPP, will be adapted internally)
- Terrain Shadow Map (calculated internally)

- Slope Map (calculated internally)

2.4.10.4 Output Data

Corrections of BOA surface reflectance retrieval for bands B01 – B12, except B10) as listed in section 2.4.11 ff. No direct user output.

2.4.11 Surface Reflectance

2.4.11.1 Input Data

60, 20m Resolution

- Full set of Bands as specified in Section 2.2.1, Table 1, (except Band 8) resampled to corresponding resolution;
- Aerosol Map as specified in Table 19;
- Water Vapour Map as specified in Table 22;
- (Optional) Cirrus correction as specified in Section 2.4.9.4;
- (Optional) Terrain correction as specified in Section 2.4.10.4.

10 m Resolution

- Bands 2,3,4,8 as specified in Section 2.2.1, Table 1, no resampling;
- Resampled Aerosol Map as specified in Table 19;
- (Optional) Terrain correction as specified in Section 2.4.10.4

2.4.11.2 GIPP

Table 26 – 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

2.4.11.3 Metadata

None

2.4.11.4 Output Data

Table 27 – 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.
Format	JPEG 2000
Unit	Dimensionless, Unsigned Integer
Calibration and Range	1 / 4000: i.e.: Digital Numbers 0 : 4000, representing radiometric reflectance values from 0.0 to 1.0
Sampling	12 bits/pixel
Input resolution	**Generated output resolution**
B1 (443nm): 60m	60m
B2 (490nm): 10m	60m, 20m, 10m
B3 (560nm): 10m	60m, 20m, 10m
B4 (665nm): 10m	60m, 20m, 10m
B5 (705nm): 20m	60m, 20m
B6 (740nm): 20m	60m, 20m
B7 (783nm): 20m	60m, 20m
B8 (842nm): 10m	10m
B8a (865nm): 20m	60m, 20m
B9 (945nm): 60m	60m
B10 (1375): 60m	No output generated as it does not contain surface information
B11 (1610nm): 20m	60m, 20m
B12 (2190nm): 20m	60m, 20m

2.5 Post Processing

2.5.1 Input Data

All outputs from previous sections.

2.5.2 Output Data

Level 2A User product formatted as sketched below and specified in detail in [S2-L2A-PFS].

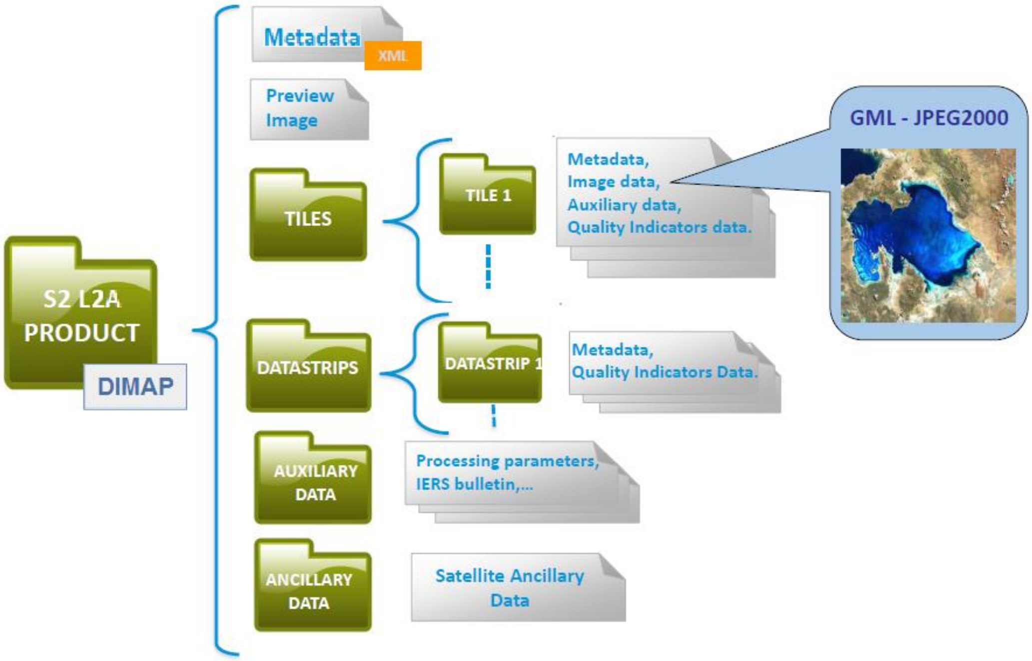

Figure 2-4 – Level 2A product, physical format

3. APPENDIX: EXAMPLE OF GIPP FILE


```xml
<?xml version="1.0" encoding="UTF-8"?>
<Level-2A_Ground_Image_Processing_Parameter>
  <Common_Section>
    <Trace_Level>DEBUG</Trace_Level> <!-- can be: NOTSET, DEBUG, INFO, WARNING, ERROR, CRITICAL --
>
    <DN_Scale>4000.0</DN_Scale>
    <DEM_Directory>dem/srtm</DEM_Directory> <!-- should be either a directory tree under
S2L2APPHOME or 'false'. If false, no DEM will be used -->
    <DEM_Reference>http://data_public:GDdci@data.cgiar-csi.org/srtm/tiles/GeoTIFF/</DEM_Reference>
<!-- will be ignored if DEM is false. Either a DEM will be downloaded from this reference, if no local DEM is
available -->
  </Common_Section>
  <Scene_Classification>
          <Snow_Map_Reference>GlobalSnowMap.tiff</Snow_Map_Reference>
    <Classificators>
      <NO_DATA>0</NO_DATA>
      <SATURATED_DEFECTIVE>1</SATURATED_DEFECTIVE>
      <DARK_FEATURES>2</DARK_FEATURES>
      <CLOUD_SHADOWS>3</CLOUD_SHADOWS>
      <VEGETATION>4</VEGETATION>
      <BARE_SOILS>5</BARE_SOILS>
      <WATER>6</WATER>
      <LOW_PROBA_CLOUDS>7</LOW_PROBA_CLOUDS>
      <MEDIUM_PROBA_CLOUDS>8</MEDIUM_PROBA_CLOUDS>
      <HIGH_PROBA_CLOUDS>9</HIGH_PROBA_CLOUDS>
      <THIN_CIRRUS>10</THIN_CIRRUS>
      <SNOW_ICE>11</SNOW_ICE>
    </Classificators>
    <Calibration>
      <Median_Filter>3</Median_Filter>
    </Calibration>
    <Thresholds>
      <T1_B02>0.18</T1_B02>
      <T2_B02>0.22</T2_B02>
      <T1_B04>0.08</T1_B04>
      <T2_B04>0.25</T2_B04>
      <T1_B8A>0.15</T1_B8A>
      <T2_B8A>0.35</T2_B8A>
      <T1_B10>0.012</T1_B10>
      <T2_B10>0.035</T2_B10>
      <T1_B12>0.25</T1_B12>
      <T2_B12>0.12</T2_B12>
      <T_B02_B12>0.018</T_B02_B12>
      <T_CLOUD_LP>0.0</T_CLOUD_LP>
      <T_CLOUD_MP>0.35</T_CLOUD_MP>
      <T_CLOUD_HP>0.65</T_CLOUD_HP>
      <T1_NDSI_CLD>-0.24</T1_NDSI_CLD>
      <T2_NDSI_CLD>-0.16</T2_NDSI_CLD>
      <T1_NDSI_SNW>0.20</T1_NDSI_SNW>
      <T2_NDSI_SNW>0.42</T2_NDSI_SNW>
      <T1_NDVI>0.36</T1_NDVI>
      <T2_NDVI>0.47</T2_NDVI>
```

```
        <T1_SNOW>0.12</T1_SNOW>
        <T2_SNOW>0.25</T2_SNOW>
        <T1_R_B02_B04>0.85</T1_R_B02_B04>
        <T2_R_B02_B04>0.95</T2_R_B02_B04>
        <T1_R_B8A_B03>1.50</T1_R_B8A_B03>
        <T2_R_B8A_B03>2.50</T2_R_B8A_B03>
        <T1_R_B8A_B11>0.90</T1_R_B8A_B11>
        <T2_R_B8A_B11>1.10</T2_R_B8A_B11>
        <T11_B02>-0.40</T11_B02>
        <T12_B02>0.46</T12_B02>
        <T11_R_B02_B11>0.8</T11_R_B02_B11>
        <T12_R_B02_B11>1.5</T12_R_B02_B11>
        <T21_R_B02_B11>2.00</T21_R_B02_B11>
        <T22_R_B02_B11>4.00</T22_R_B02_B11>
        <T21_B12>0.1</T21_B12>
        <T22_B12>-0.09</T22_B12>
        <RV_B2>6.96000</RV_B2>
        <RV_B3>5.26667</RV_B3>
        <RV_B4>5.37708</RV_B4>
        <RV_B8>7.52000</RV_B8>
        <RV_B11>5.45000</RV_B11>
        <RV_B12>2.55000</RV_B12>
        <T_SDW>0.75</T_SDW>
      </Thresholds>
    </Scene_Classification>
    <Atmospheric_Correction>
      <References>
        <Lib_Dir>lib</Lib_Dir>
        <Atm_Data_Filename>h99000_wv20_rura.atm</Atm_Data_Filename>
      </References>
      <Flags>
        <WV_Correction>1</WV_Correction>
        <VIS_Update_Mode>1</VIS_Update_Mode> <!-- 0: constant, 1: variable visibility -->
        <WV_Watermask>1</WV_Watermask> <!-- 0: not replaced, 1: land-average, 2: line-average -->
        <Cirrus_Correction>1</Cirrus_Correction>
        <BRDF_Correction>0</BRDF_Correction>
        <BRDF_Lower_Bound>0.25</BRDF_Lower_Bound>
      </Flags>
      <Calibration>
        <DEM_Unit>0</DEM_Unit> <!-- (0=[m], 1=[dm], 2=[cm]) -->
        <Adj_Km>1.000</Adj_Km> <!-- [km] -->
        <Visibility>30.0</Visibility> <!-- [km] -->
        <Altitude>0.100</Altitude> <!-- [km] -->
        <Smooth_WV_Map>100.0</Smooth_WV_Map> <!-- length of square box, [meters] -->
        <WV_Threshold_Cirrus>0.25</WV_Threshold_Cirrus> <!-- water vapor threshold to switch off cirrus
algorithm [cm] -->
      </Calibration>
      <Sensor>
        <Solar_Irradiance units = "[mW/cm2 micron]">
          <Band_List>
            <wavelength fwhm="0.018800" e0="187.282">0.442250</wavelength>
            <wavelength fwhm="0.064400" e0="195.995">0.492225</wavelength>
            <wavelength fwhm="0.034800" e0="182.252">0.560310</wavelength>
            <wavelength fwhm="0.028800" e0="151.628">0.663085</wavelength>
            <wavelength fwhm="0.014400" e0="142.487">0.703959</wavelength>
            <wavelength fwhm="0.014800" e0="128.363">0.742381</wavelength>
```

```
        <wavelength fwhm="0.018800" e0="116.686">0.781725</wavelength>
        <wavelength fwhm="0.014400" e0="104.008">0.833331</wavelength> <!-- B8 -->
        <wavelength fwhm="0.022800" e0="095.447">0.865816</wavelength> <!-- B8A -->
        <wavelength fwhm="0.019200" e0="081.983">0.942251</wavelength>
        <wavelength fwhm="0.028800" e0="036.705">1.373680</wavelength>
        <wavelength fwhm="0.088400" e0="024.734">1.609431</wavelength>
        <wavelength fwhm="0.172800" e0="008.649">2.193888</wavelength>
      </Band_List>
    </Solar_Irradiance>
    <Calibration units = "(mW cm-2 sr-1 um-1), L = c0 + c1 * DN">
      <Band_List>
        <wavelength c0="0.00000" c1="0.1">0. 442250</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 492225</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 560310</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 663085</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 703959</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 742381</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 781725</wavelength>
        <wavelength c0="0.00000" c1="0.1">0. 833331</wavelength> <!-- B8 -->
        <wavelength c0="0.00000" c1="0.1">0. 865816</wavelength> <!-- B8A -->
        <wavelength c0="0.00000" c1="0.1">0. 942251</wavelength>
        <wavelength c0="0.00000" c1="0.1">1. 373680</wavelength>
        <wavelength c0="0.00000" c1="0.1">1. 609431</wavelength>
        <wavelength c0="0.00000" c1="0.1">2. 193888</wavelength>
      </Band_List>
    </Calibration>
  </Sensor>
 </Atmospheric_Correction>
</Level-2A_Ground_Image_Processing_Parameter>
```