Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Input/output data specification for the TROPOMI L01b data processor

document number : S5P-KNMI-L01B-0012-SD
CI identification : CI-6510-IODS
issue : 4.0.0
date : 2014-12-09
status : released

Document approval record

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Document change record

Issue	Date	Item	Comments
0.1.0	2012-12-03	All	Prepared for review.
0.2.0	2013-02-13	All	Processed informal review comments; see S5P-KNMI-L01B-1012-LI-RLF issue A.4.
1.0.0	2013-03-05	All	Modifications based on comments received on version 0.2.0. Editorial modifications.
1.0.1	2013-07-12	All	New sections on metadata (sections 7, 8 and 10.2). New section on input data (section 5). Redefinition of time variable. Redefinition of noise and error variables for radiance and irradiance. spectral_wavelength removed (radiance). spectral_wavelength replaced by calibrated_wavelength (irradiance). Reformatting of tables. Updated section 9.1 on L1b file structure.
1.0.2	2013-08-29	All	Modifications based on comments from internal review. Measurement class renamed to Processing class. Slicing for NRT products. Redefinition of quality_level. New TROPOMI logo
1.1.0	2013-09-11	All	Updated section on variable attributes Editorial modifications
1.2.0	2013-11-20	All	Processed formal review comments; see S5P-KNMI-L01B-1012-LI-RLF issue B.3.
2.0.0	2013-12-05	All	Modifications based on comments received on version 1.2.0. Editorial modifications.
2.1.0	2014-06-05	All	Document ported from Word to LaTeX. Definition of engineering product added (section 7.3.4). Product sizes table updated (Appendix A). Processing classes table updated (Appendix B). Type of variable time changed to int (section 8.5). Variables time and delta_time moved to ObservationsGroup (sections 7.3.1 and 7.3.2). Variables radiance, irradiance and small_pixel_radiance are normalized to 1AU. Variable descriptions added for instrument_settings, binning_table, housekeeping_data (sections 8.41 - 8.43). Moved sections on metadata models and profiles to document [RD9]).
2.2.0	2014-06-27	All	Modifications resulting from review comments. Ordering of dimensions in netCDF product changed.
2.3.0	2014-07-07	All	Some additional modifications resulting from review comments.
3.0.0	2014-07-07	All	Some additional modifications resulting from review comments.
3.0.1	2014-10-31	All	EO-FFS Fixed Header example added.
3.0.2	2014-11-18	All	Corrected EO-FFS example.
4.0.0	2014-12-09	All	Prepared for processor release 0.8.0

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1 Introduction

1.1 Identification

This document, identified by S5P-KNMI-L01B-0012-SD, describes the data format of the TROPOMI Level-1b (L1b) data products. The logic for the L1b data format results from an analysis of different applicable standards and best practices in the Earth Observation (EO) data field. This document is identified in [AD1] as CI-6510-IODS.

1.2 Purpose and objective

The TROPOMI L01b processor developed by KNMI produces L1b data products from L0 input data and auxiliary data products. The TROPOMI L1b data products distinguish radiance, irradiance, calibration and engineering data. Although these products differ in their applicability, the objective is to define a common data format for all TROPOMI L1b products.

This document mainly addresses the output data of the L01b processor (i.e. the L1b data products), providing detailed specifications of the different L1b products. The input data (the Level 0 products and the various auxiliary products) are also identified and summarized in this document. One type of auxiliary data product is the calibration key data. Document [RD10] describes the types of calibration key data files. Also the detailed specification of the L0 products will become available in a separate document [AD2].

1.3 Document overview

This document describes the official products that are the result from the Level 0 to Level 1b processing of the data collected by TROPOMI onboard the Sentinel-5 Precursor satellite. For all of the defined data products detailed technical information with respect to their contents and data formats is provided. This allows processing facilities and scientists to develop software for extracting information and in particular to produce higher level (i.e. Level 2) products.

The document is based on the results of discussions with user communities and of studies on data interoperability standards and on the lessons learned from previous missions (i.e. OMI),

After a short introduction of the TROPOMI system, its mission, the geophysical phenomena studied and the parameters measured by the detectors, the L1b products are described. Product specifications are presented in terms of file naming, file format and file structure. Comprehensive descriptions and specifications of all variables contained in the products are presented.

2 Applicable and reference documents

2.1 Applicable documents

[AD1] Software development plan for TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0002-PL; **issue:** 2.0.0; **date:** 2012-11-14.

[AD2] Sentinel-5 precursor PDGS Level-0 product format.
source: DLR; **ref:** S5P-PDGS-DLR-ISP-3011; **issue:** 1.1 Draft; **date:** 2014-05-23.

[AD3] Software product assurance plan for TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0003-PL; **issue:** 2.0.0; **date:** 2012-11-14.

[AD4] Software system specification for TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0005-RS; **issue:** 3.0.0; **date:** 2012-11-21.

[AD5] Tailoring of the Earth Observation File Format Standard for the Sentinel 5-Precursor Ground Segment.
source: ESA; **ref:** S5P-TN-ESA-GS-106; **issue:** 2.1; **date:** 2013-06-07.

[AD6] Earth Observation Ground Segment File Format Standard.
source: ESA; **ref:** PE-TN-ESA-GS-0001; **issue:** 2.0; **date:** 2012-05-03.

2.2 Standard documents

[SD7] Space Engineering – Software.
source: ESA/ECSS; **ref:** ECSS-E-ST-40C; **date:** 2009-03-06.

[SD8] Space Product Assurance – Software Product Assurance.
source: ESA/ECSS; **ref:** ECSS-Q-ST-80C; **date:** 2009-03-06.

2.3 Reference documents

[RD9] Metadata specification for the TROPOMI L1b products.
source: KNMI; **ref:** S5P-KNMI-L01B-0014-SD; **issue:** 2.0.0; **date:** 2014-12-09.

[RD10] Calibration key data specification for the TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0028-SD; **issue:** 2.0.0; **date:** 2014-12-09.

[RD11] Terms, definitions and abbreviations for TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0004-LI; **issue:** 3.0.0; **date:** 2013-11-08.

[RD12] Algorithm theoretical basis document for the TROPOMI L01b data processor.
source: KNMI; **ref:** S5P-KNMI-L01B-0009-SD; **issue:** 5.0.0; **date:** 2014-12-09.

[RD13] NetCDF Climate and Forecast (CF) Metadata Conventions.
source: CFConventions; **ref:** n/a; **issue:** 1.6; **date:** 2011-12-05.

[RD14] INSPIRE Metadata Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119.
source: EC JRC; **ref:** MD_IR_and_ISO_v1_2_20100616; **issue:** 1.2; **date:** 2010-06-16.

[RD15] Earth Observation Metadata profile of Observations Measurements.
source: OGC; **ref:** OGC 10-157r4; **issue:** 1.0.3-DRAFT; **date:** 2014-01-10.

[RD16] Command and Telemetry Handbook.
source: Dutch Space; **ref:** TROP-DS-0000-RP-0579; **issue:** 2.1; **date:** 2013-05-16.

2.4 Electronic references

[ER17] http://www.iers.org.

[ER18] http://www.unidata.ucar.edu/software/netcdf/docs/.

[ER19] http://en.wikipedia.org/wiki/University_Corporation_for_Atmospheric_Research.

[ER20] http://wiki.esipfed.org/index.php/Category:Attribute_Conventions_Dataset_Discovery.

[ER21] http://www.unidata.ucar.edu/software/thredds/current/tds/.

[ER22] http://wiki.esipfed.org/index.php/NetCDF,_HDF,_and_ISO_Metadata.

3 Terms, definitions and abbreviated terms

Terms, definitions and abbreviated terms that are used in the development program for the TROPOMI L01b data processor are described in [RD11]. Terms, definitions and abbreviated terms that are specific for this document can be found below.

3.1 Terms and definitions

There are no terms and definitions specific to this document.

3.2 Acronyms and Abbreviations

ACDD	Attribute Convention for Dataset Discovery
APID	Application Process Identifier
ADN	ADEPT/DLESE/NASA
AQA	Automated Quality Assurance
AU	Astronomical Unit
CCSDS	Consultative Committee for Space Data Systems
CF	Climate and Forecast
CKDS	Calibration Key Data Set
DEM	Detector Electronics Module
DIF	Data Interchange Format
EC	European Commission
EO-FFS	Earth Observation Ground Station File Format Standard
EOP	Earth Observation Product
ESA	European Space Agency
ESIP	Federation of Earth Science Information Partners
EU	European Union
FGDC	Federal Geographic Data Committee
GEMET	GEneral Multilingual Environmental Thesaurus
GMES	Global Monitoring for Environment and Security
HDF	Hierarchical Data Format
HMA	Heterogeneous Mission Accessibility
IcID	Instrument Configuration ID
ID	Identifier
IERS	International Earth Rotation and Reference Systems Service
INSPIRE	Infrastructure for Spatial Information in the European Community
IODS	Input/Output Data Specification
ISM	Instrument Specific Module
JRC	Joint Research Centre
LED	Light-Emitting Diode
LTAN	Local Solar Time at Ascending Node
NcML	NetCDF Markup Language
NetCDF	Network Common Data Form
NRT	Near Real Time
NUG	NetCDF User Guide
OGC	Open Geospatial Consortium
QI	Quality Indicator
SAA	South Atlantic Anomaly

SZA	Solar Zenith Angle
THREDDS	Thematic Realtime Environmental Distributed Data Services
TOA	Top Of Atmosphere
UCAR	University Corporation for Atmospheric Research
UML	Unified Modeling Language
UTC	Coordinated Universal Time
WGS	World Geodetic System
WLS	White Light Source
XML	Extensible Markup Language

4 TROPOMI system overview

4.1 Mission

The Sentinel-5 Precursor (S5p) mission will be implemented as part of the Global Monitoring for Environment and Security (GMES) programme, which is a joint initiative of the European Commission (EC) and of the European Space Agency (ESA). The S5p mission is a single-payload satellite in a low Earth orbit that provides daily global information on concentrations of trace gases and aerosols important for air quality, climate forcing, and the ozone layer. The payload of the mission is the TROPOspheric Monitoring Instrument (TROPOMI), which is jointly developed by The Netherlands and ESA. TROPOMI is a spectrometer with spectral bands in the ultraviolet (UV), the visible (VIS), the near-infrared (NIR) and the shortwave infrared (SWIR). The selected wavelength range for TROPOMI allows observation of key atmospheric constituents, including ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), sulfur dioxide (SO_2), methane (CH_4), formaldehyde (CH_2O), aerosols and clouds.

4.2 Instrument description

The TROPOMI instrument (TROPOMI) is a space-borne nadir-viewing hyperspectral imager with four separate spectrometers covering non-overlapping and non-contiguous wavelength bands between the ultraviolet and the shortwave infrared. The instrument is the payload on the ESA/GMES Sentinel 5 Precursor mission.

The purpose of TROPOMI is the measurement of atmospheric properties and constituents. The instrument uses passive remote sensing techniques to attain its objective by measuring at the top of the atmosphere the solar radiation reflected by and radiated from the Earth. The instrument operates in a push-broom configuration with a wide swath. Light from the entire swath is recorded simultaneously and dispersed onto two-dimensional imaging detectors: the position along the swath is projected onto one direction of the detectors, and the spectral information for each position is projected on the other direction.

The instrument images a strip of the Earth on a two dimensional detector for a period of approximately 1 second during which the satellite moves by about 7 km. This strip has dimensions of approximately 2600 km in the direction across the track of the satellite and 7 km in the along-track direction. After the 1 second measurement a new measurement is started thus the instrument scans the Earth as the satellite moves. The two dimensions of the detector are used to detect the different ground pixels in the across track direction and for the different wavelengths. The measurement principle of TROPOMI is shown in Figure 1.

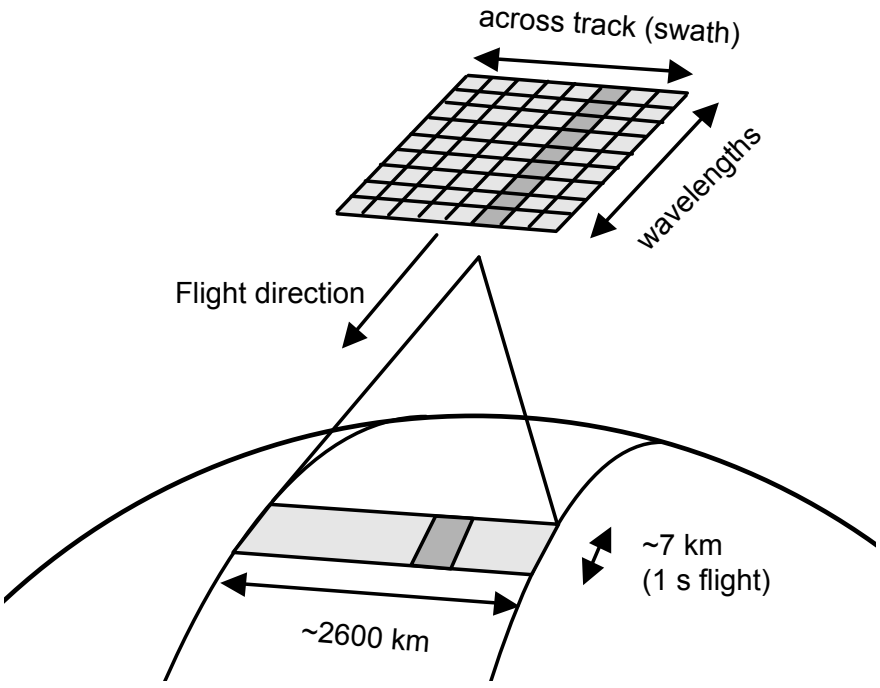

Figure 1: TROPOMI measurement principle

TROPOMI utilizes a single telescope to form an image of the target area onto a rectangular slit that acts as the entrance slit of the spectrometer system. There are four different spectrometers, each with its own optics and detector: medium wave ultraviolet (UV), long wave ultraviolet combined with visual (UVIS), near infrared (NIR), and short wave infrared (SWIR). The spectrometers for UV, UVIS and NIR are jointly referred to as UVN. Table 1 lists the spectral characteristics of the four TROPOMI spectrometers and the definition of the TROPOMI spectral bands with identifiers 1–8.

Instrument module	**UVN**						**SWIR**	
Detector	**UV**		**UVIS**		**NIR**		**SWIR**	
Band ID	1	2	3	4	5	6	7	8
Spectral range [nm]	270–300	300–320	320–405	405–500	675–725	725–775	2305–2345	2345–2385
Spectral resolution [nm]	0.5	0.5	0.5	0.5	0.5	0.5	0.23	0.23
Spectral sampling [nm/pixel]	0.065	0.065	0.20	0.20	0.124	0.124	0.084	0.097

Table 1: Main spectral characteristics of the four TROPOMI spectrometers and the definition of the spectral bands with identifiers 1–8. Remark: the figures mentioned for range, resolution and sampling are taken from [RD12]. These figures might change in future releases of [RD12]; this table will be updated accordingly in next issues.

4.3 Instrument operations

For TROPOMI instrument operations, an orbital scheduling approach is used. An orbit is defined from spacecraft midnight to spacecraft midnight. Earth radiance measurements will be performed on the day side of the orbit. At the north side of the orbit, near the day-night terminator, the Sun is visible in the instrument's solar port. Approximately once a day, a solar irradiance measurement is performed. The night side of the orbit is used for calibration and background measurements. The following constraints apply to the calibration measurements:

1. Background and calibration measurements can only be performed when the spacecraft is in eclipse.
2. No measurements can be taken around spacecraft midnight, in order to facilitate data processing.
3. All orbits must contain background measurements in the eclipse part of the orbit that match the radiance measurements on the day side for in-orbit calibration by the L01b Processor.
4. Calibration measurements must be performed outside the South Atlantic Anomaly (SAA) area, in order to minimize interference of proton radiation.
5. Calibration measurements must have a regular, fixed repetition interval.

In Figure 2 the Sentinel-5p orbit overview is presented. Each S5p orbit has a day (lit) side and a night (dark) side, as illustrated in the figure. On the day side the spacecraft flies from south to north; on the night side it flies from north to south. Spacecraft midnight is defined as the time halfway the nadir day-night terminator and the nadir night-day terminator; spacecraft noon is the time halfway the nadir night-day terminator and the nadir day-night terminator. Both the instrument operations as well as data processing will use the spacecraft midnight as the start and end points of an orbit. Due to seasonal variation, the position of the equator with respect to the spacecraft midnight will change. As a result, spacecraft midnight is not at a fixed latitude.

The S5p reference orbit is a near-polar frozen sun-synchronous orbit, adopted for mission optimization with a mean Local Solar Time at Ascending Node (LTAN) of 13:30 h and a repeat cycle of 17 days or 24155 orbits. More important than this repeat cycle is the operational repeat cycle. To accommodate regular, fixed repetition intervals for the calibration measurements, a scheme of 360 orbits is used. As 360 is divisible by many numbers, it is possible to accommodate many different repetition intervals. For sake of simplicity, the 360 orbits are divided in 24 blocks of 15 orbits, each block corresponding to approximately 25 hours, or roughly to a day. A 'week' is defined to be 6 of these 15-orbit blocks and a 'month' as 4 of these weeks. This allows for easy definition of calibration measurements that have (roughly) daily, weekly, biweekly or monthly repetition cycles.

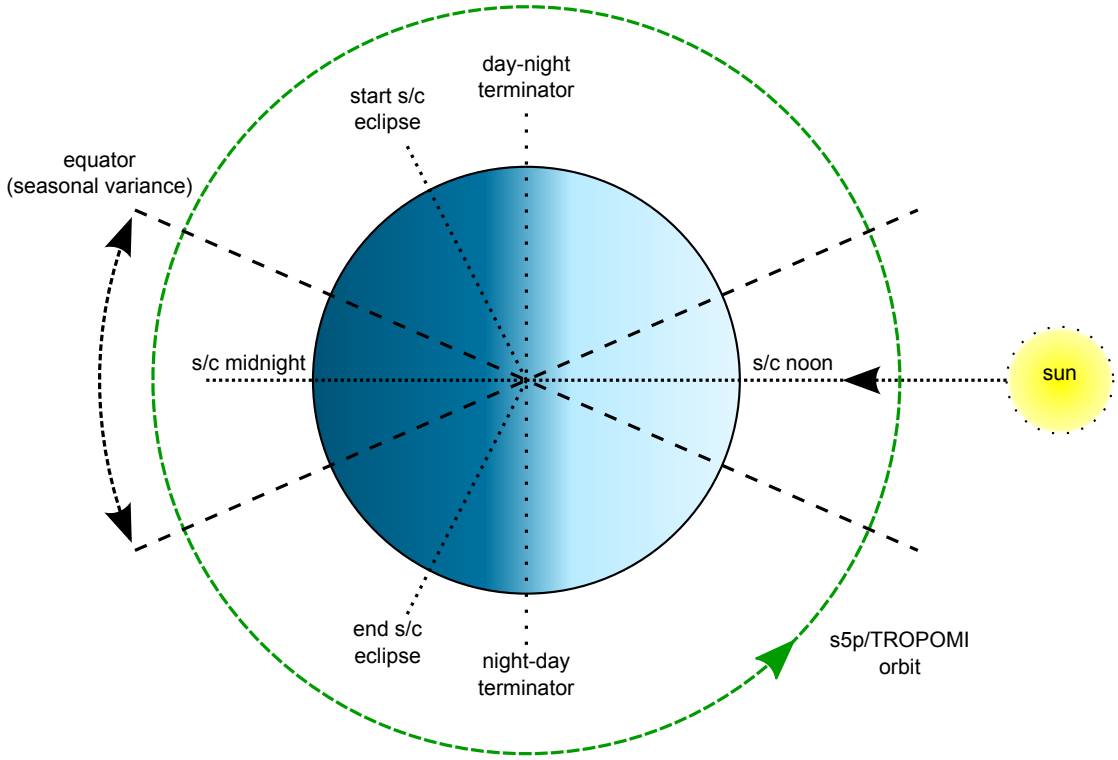

Figure 2: Sentinel-5p orbit overview

4.3.1 Co-addition and small pixels

The signals detected by the spectrometers are digitized in the detector electronics modules (DEMs). The data is saved and co-added in the instrument specific modules (ISMs) in the instrument control unit (ICU). The number of those pixels to be co-added for each detector half (or band) is individually programmable between 0 and 512. It is possible to co-add up to 256 consecutive images. The two halves of one detector can use different co-addition factors.

Information concerning the individual signals of a pixel that contribute (i.e. add up to) to a co-addition is lost, with one exception. One configurable detector pixel, in every row, for both detector output chains, i.e., two columns per detector, is also stored separately for every exposure/co-addition of an image. The data for these 'small-pixel columns' are included in the science data and provide information on a higher spatial resolution than the data for other columns, which may be useful for certain studies.

Clearly, co-addition increases the signal to noise ratio. Pixels in the small pixel columns are excluded from this operation. These pixels provide the only way to get some information about changes in a temporal sense during the co-addition time.

4.3.2 Earth radiance measurements

The Earth radiance measurements form the bulk of the measurements. Apart from the optical properties of the instrument, there is some flexibility in the electronics that determines the Earth radiance ground pixel size. The co-addition period determines the ground pixel size in the along-track direction. Row binning (which is possible for UVN detector modules only) determines the ground pixel size cross-track.

For the Earth radiance measurements, the co-addition period will be set to 1080 ms. This effectively results in a ground pixel size of approximately 7 km along-track. For the SWIR-DEM, which contains a CMOS detector, row binning is not supported. This means that, effectively, the binning factor is 1 for the SWIR bands, resulting in a ground pixel size across-track between 7 km at the center and 34 km at the edges of the across-track field of view.

The binning factors and across-track ground pixel size are summarized in Table 2 (taken from [RD12]).

Band	DEM	Binning factor	Across-track ground pixel size
1	UV	8...16	28 ... 68 km
2	UV	2...4	7 ... 17 km
3	UVIS	2...4	7 ... 17 km
4	UVIS	2...4	7 ... 17 km
5	NIR	2...4	7 ... 17 km
6	NIR	1...2	3.5 ... 8.5 km
7	SWIR	n/a	7 ... 34 km
8	SWIR	n/a	7 ... 34 km

Table 2: Binning factors and across-track ground pixel sizes for Earth radiance measurements

4.3.3 Solar irradiance measurements

The Sun is visible in TROPOMI's solar irradiance port every orbit for a period of approximately 1.5 minutes around orbit phases 0.75[1]. Every 15 orbits - approximately once every calendar day - TROPOMI will be commanded to perform a solar irradiance measurement. As the main purpose of the solar irradiance measurement is to calculate top-of-atmosphere reflectance, the solar irradiance measurement follows the same binning scheme as the Earth radiance measurements. The remaining parameters will be optimized for the best signal-to-noise ratio. The signal-to-noise ratio is improved even further by averaging the solar irradiance measurements within the L01b Processor.

4.3.4 Background measurements

The background signal for measurements will be calibrated in-orbit. For this to work, every measurement should have accompanying background measurements in the same orbit. These background measurements are performed using the exact same settings as the measurement they accompany. A different IcID for the background measurement ensures that on-ground it is being processed as a background measurement. The background measurements are performed on the eclipse side of the orbit.

4.3.5 Calibration measurements

Calibration measurements will be performed on the night side of the orbit, outside the SAA. The binning scheme that is used for a calibration measurement depends on the objective of that measurement. Calibration measurements that have a strong relation with Earth radiance measurements will use the same binning scheme as Earth radiance measurements. Most calibration measurements however will use a so-called unbinned scheme, that reads out all the pixels of the detector. For these measurements, the co-addition period may be slightly longer than for Earth radiance measurements, to avoid data rate bottlenecks within the instrument or the platform.

Since for instrument operations, the orbits are defined without any seasonal dependency, only a small part of the orbit is guaranteed to be unaffected by the SAA throughout the seasons. This part of the orbit will be used for calibration measurements, while the remainder of the orbit where the spacecraft is in eclipse will be used for background measurements. This is shown in Figure 3. These background measurements are susceptible for proton radiation too, but the L01b Processor will use a filter to avoid background measurements taken in the SAA being used for in-orbit calibration

[1] The orbit phase is defined as $1/(2\pi)$ times the angle in radians traversed by the spacecraft since spacecraft midnight as seen from the center of the Earth. Spacecraft midnight is the point on the night side of the Earth where the spacecraft crosses the orbital plane of the Earth about the Sun. This makes the orbit phase a quantity that runs from 0 to 1, while the spacecraft moves between each spacecraft midnight.

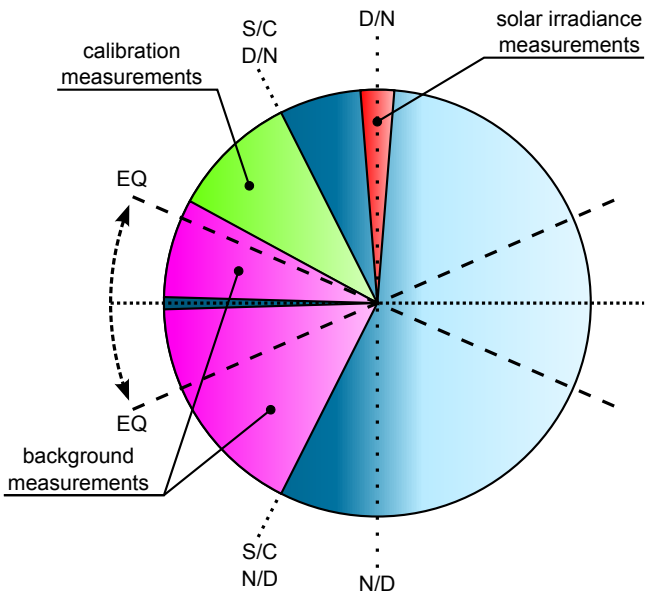

Figure 3: Position of irradiance, calibration and background measurements in the orbit. S/C = spacecraft, EQ = equator, D = day, N = night.

5 Input data products

The main inputs for the L01b are the L0 data products, as described in Table 3. Each of these L0 data products will contain L0 data of a different Application Process Identifier (APID), i.e. 1 APID per product, separate products for each of the APIDs. The L0 product format is specified in [AD2].

Input product	Description
L0_ENG	L0 Engineering data (X-Band telemetry)
L0_ID1 . . . L0_ID8	L0 Instrument data band for bands 1 through 8
L0_ANC	L0 Ancillary data (containing S/C ephemeris and attitude)

Table 3: L0 input products

Another important input for the L01b is the Calibration Key Data. It is foreseen that the Calibration Key Data is provided as a set of data products that has a specified validity range (i.e. the set of orbits to which these Calibration Key Data can be applied and as described in metadata). For the production rules, such a Calibration Key Data Set (CKDS) is treated as an auxiliary data product. The frequency at which the CKDS will be updated depends on the performance of the instrument; a first assumption is that daily updates will be made available. The CKDS is described in [RD10]. An overview of all the auxiliary data products that are currently foreseen is provided in Table 4.

Input product	Description
CKDS	Calibration Key Data Set
IERSB	IERS Bulletin B, see [ER17]. The IERS Bulletin B files can be obtained using anonymous FTP from the IERS public FTP server ftp.iers.org in directory `ftp://ftp.iers.org/products/eop/bulletinb/format_2009/`. These products are generated once per month and are approximately 17 kB in size.
IERSC	IERS Bulletin C, see [ER17]. The IERS Bulletin B files can be obtained using anonymous FTP from the IERS public FTP server ftp.iers.org in directory `ftp://ftp.iers.org/products/eop/bulletinc/`. These products are generated approximately twice per year and are approximately 2 kB in size.

Table 4: L0 auxiliary input products

Finally, there are several static input files that determine the run-time configuration of the L01b. These will be delivered with the L01b and are considered part of the run-time environment of the L01b. These files are, for example, used to tailor the L01b for a specific processing mode. This means that for each of the different modes, there will / can be separate deliveries of the L01b. These deliveries could differ in terms of binaries or in term of these static input files or both.

6 TROPOMI L1b product overview

The Level-1b processor output consists of the following data products:

Level-1b radiance The Level-1b radiance products contain the Earth radiance measurements, including annotation data such as geolocation. For each data granule, typically of the size of one orbit, there is a data product for each of the eight bands. The radiance products are the main input for the Level-2 processors.

Level-1b irradiance The Level-1b irradiance products contain the averaged solar irradiance measurements, including annotation data. For each data granule, there is a data product for each of the two modules, UVN and SWIR. The Level-2 processors will use the irradiance products to calculate reflectance from the Earth radiance data. The irradiance data is used for calibration processing as well. Every 15 orbits - approximately once every calendar day - TROPOMI will be commanded to perform a solar irradiance measurement. If no solar measurements are available in the data granule being processed, no irradiance product will be generated.

Level-1b calibration The Level-1b calibration products contain the calibration and background measurements, including annotation data, as well as any calibration data that are derived from radiance and irradiance measurements. For each data granule, there is a data product for each of the two modules, UVN and SWIR. The calibration products are the main input for the calibration processors that will use these products for generating updates to the calibration key data and for generating trending and monitoring products.

Level-1b engineering The Level-1b engineering products contain the instrument's engineering data converted to physical units. For each data granule, there is a single data product. The engineering products are input for the calibration processors who will use these products for generating updates to the calibration key data and for generating trending and monitoring products. The L1b engineering product is only intended for calibration and monitoring purposes. All instrument information needed or relevant for L2 processing will be contained within the radiance and irradiance products. The operational perspective of the L01b processing chain is depicted in Figure 4.

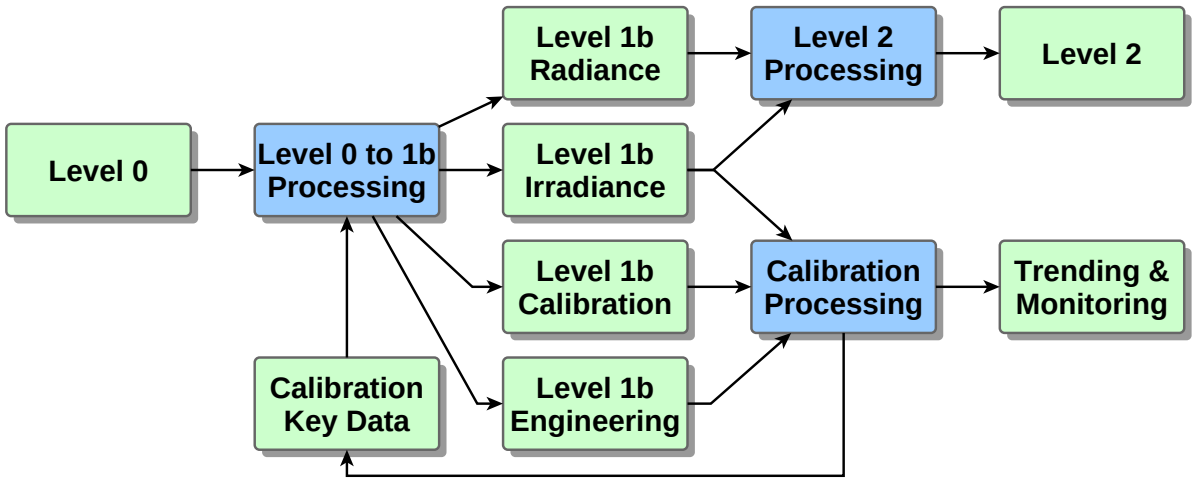

Figure 4: Operational perspective of the L01b processing chain, showing its data products and their position in the processing chain. The blue blocks denote processors; the green blocks denote data products.

The L01b Processor is operationally used in two different modes: **standard product processing** and **near-real-time (NRT) product processing**. The products from standard product processing have the highest quality but less stringent requirements for timeliness. This as opposed to the NRT products, which are required to be available within 2 hours 15 minutes after observation for L1b and 3 hours after observation for L2. To achieve this requirement, speed is favored over quality for the NRT products. The standard products can be distinguished from the NRT products by means of their product or file names and the metadata.

The operational perspective of the NRT processing chain differs from the standard L10b processing chain in that it not includes the generation of irradiance products nor that it involves calibration processing. This is show in Figure 5.

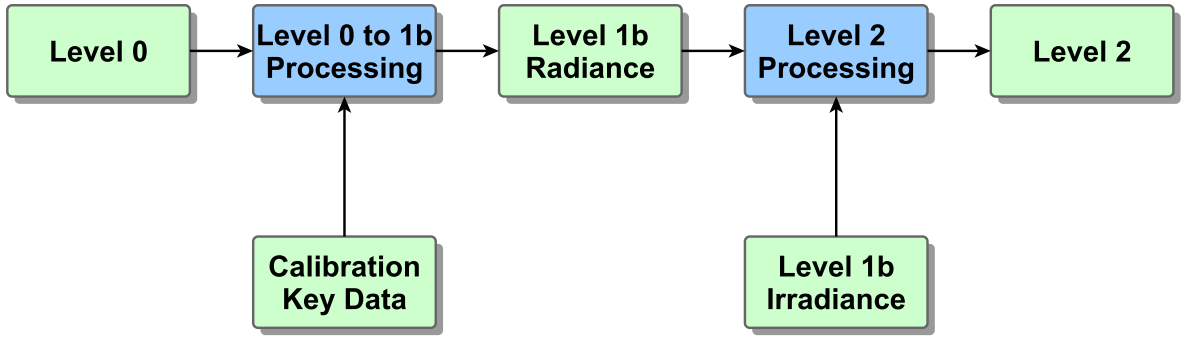

Figure 5: Operational perspective of the NRT processing chain. The blue blocks denote processors; the green blocks denote data products. The irradiance product shown is the result of the standard processing chain.

The data granule (defined as the data time span that is to be processed by the processor) is one orbit for standard product processing. For reasons of efficiency (i.e. data transmission), the volume of one data downlink will be sliced into smaller data volumes. These smaller data volumes form the base of the NRT products, leading approximately to 1 NRT product per data slice.

Table 5 presents an overview of the products: two radiance products will be made for each detector (one for each spectral band). Irradiance and calibration products are instrument module specific.

Instrument module	**UVN**						**SWIR**	
Detector	**UV**		**UVIS**		**NIR**		**SWIR**	
Spectral band	1	2	3	4	5	6	7	8
Radiance product (standard) (# of products/orbit)	1	1	1	1	1	1	1	1
Radiance product (NRT) (# of products/orbit)	10-20	10-20	10-20	10-20	10-20	10-20	10-20	10-20
Irradiance product (# of products/day)	1 (UVN)						1 (SWIR)	
Calibration product (# of products/orbit)	1 (UVN)						1 (SWIR)	
Engineering product (# of products/orbit)	1 (UVN + SWIR)							

Table 5: Overview of L1b products that are generated per day (irradiance product) and per orbit (all other products); The number of NRT products depends on the number of downlink slices and the data volume per slice. The numbers mentions here are indicative.

7 TROPOMI L1b product description

7.1 L1b file structure

The "Earth Observation Ground Station File Format Standard (EO-FFS)" standard [AD04] is relevant to all data files exchanged between ground segment systems within the Earth Observation Missions and as such applicable for the TROPOMI L1b product. This standard provides guidance for data files structures and their encoding, naming and syntax. The EO-FFS standard is used in all recent and upcoming ESA Earth Observations missions, including Sentinel Missions 1, 2 and 3. For the Sentinel 5 Precursor ground segment a tailoring document [AD5] has been made available with a mission specific implementation of the EO-FFS standard.

Within this standard, Earth observation data files are defined as logical files composed of one header and one data block. The logical file can be structured as one physical file or as two physical files separate (i.e. a header file and data block file). The *physical header file* is defined as an XML file containing a fixed part and a variable part of header/metadata information. The header contains configuration control or organizational data. A physical header file has a file name extension ".HDR."

The *data block* can be either an ASCII/XML file or a binary file. In case of a binary file, a self-describing format is preferred. Binary data blocks are always stored as a separate file with file name extension ".DBL". For the TROPOMI L1b products the use of a binary data block is applicable containing one netCDF4 file (see section 7.2 for a discussion on netCDF4). In order to be in conformance with the CF-Metadata conventions [RD13], the tailoring permits to use the file name extension ".nc" for the physical filename instead.

For the TROPOMI L1b products this leads to the following convention with respect to the naming of the physical header and the data block files:

header file: `logical_file_name.HDR`

data block file: `logical_file_name.nc`

When these files are distributed the baseline for packaging is "zip", but other formats (i.e. "gzip", "tar" or "tar/gzip") are allowed. However, because of the considerable processing overhead introduced in compressing and decompressing L1b products, it is recommended to use either "zip" without compression or "tar" (uncompressed by definition). In case of packed files the file name extension is ".zip" or ".tar".

7.1.1 L1b logical file name convention

The files shall be named using a fixed set of elements, each of fixed size, separated by underscores "_". The file names are composed of a *Mission ID* (<MMM>), a *File Class* (<CCCC>), a *File Type* (<TTTTTTTTTT>) and a *File Instance ID* (<instanceID>):

L1b logical file name: <MMM>_<CCCC>_<TTTTTTTTTT>_<instance ID>

The next subsections show how the L1b logical file name will be based on the S5p tailoring defined in [AD5].

7.1.1.1 Mission ID and File Class

The Mission ID and File Class elements for S5p TROPOMI products are listed in Table 6.

Name	Value	Definition
MMM	S5P	Mission identifier (*fixed value: "S5P"*)
CCCC	[TEST, OGCA, GSOV, OPER, NRTI, OFFL, RPRO]	The file class refers to the type of activity for which the file is used. TEST for internal testing OGCA for on-ground calibration GSOV for ground segment overall validation, system level testing OPER for operational processing NRTI for near-real time processing OFFL for offline processing RPRO for reprocessing

Table 6: Mission identifier and file class specification

7.1.1.2 File Type

The File Type element identifies the product and consists of 10 characters, either uppercase letters, digits or underscores "_". For S5p, the File Type can be subdivided into two sub-elements of respectively 4 and 6 characters, as follows:

File Type: <TTTTTTTTTT> = <FFFF><DDDDDD>

where:

File Category: <FFFF>

Product Semantic Descriptor: <DDDDDD>

File Category The File Category element consists of 4 characters (3 uppercase letters, digits or underscores "_" + 1 underscore "_").

For the S5p TROPOMI L1b products (science data products) the File Category FFFF = L1B_

Product Semantic Descriptor The Product Semantic Descriptor must be unique for a given File Type and be as descriptive as possible. It consists of 6 characters, either uppercase letters, digits or underscores "_".

For S5p L1b data product files (radiance and irradiance data, calibration and engineering products) identified with the File Type element set to "L1B_", the Product Semantic Descriptor is defined as shown in Table 7.

Product Semantic Descriptor	Comment
RA_BD1	Radiance product band 1 (UV detector)
RA_BD2	Radiance product band 2 (UV detector)
RA_BD3	Radiance product band 3 (UVIS detector)
RA_BD4	Radiance product band 4 (UVIS detector)
RA_BD5	Radiance product band 5 (NIR detector)
RA_BD6	Radiance product band 6 (NIR detector)
RA_BD7	Radiance product band 7 (SWIR detector)
RA_BD8	Radiance product band 8 (SWIR detector)
IR_UVN	Irradiance product UVN module
IR_SIR	Irradiance product SWIR module
CA_UVN	Calibration product UVN module
CA_SIR	Calibration product SWIR module
ENG_DB	Engineering product

Table 7: Product Semantic Descriptor for L1b products. See Table 1 for a definition of the bands, modules and detectors.

7.1.1.3 File Instance ID

For science data products (with the File Type "L1B_"), the File Instance ID consists of 63 characters, either uppercase letters, digits or underscores "_", with the following shape:

File Instance ID: <yyyymmddThhmmss>_<YYYYMMDDTHHMMSS>_<ooooo>_<cc>
<pppppp><YYYYMMDDTHHMMSS>

where:

product start validity time: <yyyymmddThhmmss>

product stop validity time: <YYYYMMDDTHHMMSS>

absolute orbit number: <ooooo>

collection number: <cc>

processor version number: <pppppp>

production (start) time: <YYYYMMDDTHHMMSS>

Notes:

- The absolute orbit number starts at 00001 (first ascending node crossing after spacecraft separation).
- The collection number stands for a collection of parameters defining the current product (processor version, auxiliary data, and configuration settings) to ease the interpretation of data products by the end users. The collection number starts at 01.
- The processor version number consists of 6 digits, with the first 2 digits for major updates, the next 2 digits for minor updates and the last 2 digits for new releases, i.e. 010203 for processor version 1.2.3.

7.1.1.4 L1b file name examples

Hereafter (Table 8 and Table 9) some file name examples are provided of the logical file name of the different L1b products. The <instance ID> is not provided for readability.

Radiance products (standard and near real time)	Irradiance products
S5P_OPER_L1B_RA_BD1_<instance ID>	S5P_OPER_L1B_IR_UVN_<instance ID>
S5P_NRTI_L1B_RA_BD1_<instance ID>	S5P_OPER_LIB_IR_SIR_<instance ID>

Table 8: Logical file name examples for radiance and irradiance products

Calibration products	Engineering product
S5P_OPER_L1B_CA_UVN_<instance ID>	S5P_OPER_L1B_ENG_DB_<instance ID>
S5P_OPER_L1B_CA_SIR_<instance ID>	

Table 9: Logical file name examples for calibration products and engineering products

Here is a full example of the physical file name for an L1b radiance product in netCDF format, containing the radiance measurements of Band 1 (of the UVN module):

S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140_02_010203_ 20151204T093045.nc

7.1.2 L1b header file

The header presents the initial part of a logical file, containing descriptive or configuration control information. The header file (XML) distinguishes a Fixed Header and a Variable Header part. Mandatory elements of the Fixed Header part are defined in EO-FFS and are listed in [RD9]. An example of the XML formatted Fixed Header is provided in Appendix C.

The Variable Header is specific for each File Type. The EO-FFS suggests some desirable elements that may be included in the variable part, such as a description of the data block type (for L1b: *binary*), the name of input files used, if any, to generate the file and a reference to a formal document describing the format and contents of the data block. The information on input data sets and the documentation on format and contents of the data is available in the LI_Lineage metadata element of the DQ_DataQuality core element (see: [RD9]) of the ISO 19115-2 metadata specification. The approach is to copy the ISO 19139 XML representation of the LI_Lineage element into the Variable Header.

The approach for the TROPOMI L1b products is to include all the required metadata information into the product allowing the automated extraction by dedicated tools of XML formatted metadata records that are fully conformant to the INSPIRE standard [RD14], the OGC standard [RD15], which is adopted by ESA and the ESA standard [AD6]. This means that the metadata are integrated into the product independent of a metadata implementation and that tools are required to produce the standardized metadata representations. The implementation specification, including the header information is provided in section 8.2.

7.2 L1b product data structure

For the TROPOMI L1b products the netCDF-4 enhanced model has been selected as the preferred file format. NetCDF (Network Common Data Form)] [ER18] has been developed by the Unidata Program Center at the University Corporation for Atmospheric Research (UCAR) [ER19] and it is used by many scientists and application developers active in the domains of climatology, meteorology and oceanography. The netCDF-4 format is open standard and has been adopted by the Open Geospatial Consortium (OGC).

NetCDF is a data model for array-oriented scientific data. A freely distributed collection of access libraries implementing support for that data model, and a machine-independent format are available. Together, the interfaces, libraries, and format support the creation, access, and sharing of multi dimensional scientific data. NetCDF is self-documenting, which means it can internally store information used to describe the data. For example, the internal documentation can associate various physical quantities (such as temperature, pressure, and humidity) with spatio-temporal locations (such as points at specific latitudes, longitudes, vertical levels, and times). Three different netCDF formats are supported:

- netCDF classic model format
- netCDF 64-bit offset format
- netCDF enhanced data model format (netCDF-4/HDF5 format)

For all netCDF versions (versions 3.x and 4.x) the classic model is the default format. Compared to the classic model, the enhanced model (starting from version 4) offers some important new features such as support for *groups*, (user-defined) *vlen* (variable length) and *compound types* (structures) and *parallel I/O access*.

Although files written using the classic model have the advantage that they may be read by many applications, the use of the enhanced model, supporting groups and structures in particular, offers significant advantages. By the time TROPOMI has been launched, it is expected that many software products will be upgraded in time to support the features of the enhanced data model. Moreover, processing the L1b products to L2 will require dedicated software to be developed using software libraries that are currently available in several languages and already support these features. In view of the above, the enhanced model is used for all L1b products.

In order to support increased interoperability the L1b products shall also comply with the Climate and Forecast (CF) metadata conventions [RD13]. The CF-conventions provide a definitive description of what the data values found in each netCDF variable represent, and of the spatial and temporal properties of the data, including information about grids, such as grid cell bounds and cell averaging methods. This enables users of files from different sources to decide which variables are comparable, and is a basis for building software applications with powerful data extraction, grid remapping, data analysis, and data visualization capabilities.

For data discovery, the metadata of the L1b products shall follow some of the recommendations of the Attribute Convention for Dataset Discovery (ACDD) [ER20]. This convention describes the recommended netCDF attributes for describing a netCDF dataset for use by discovery systems. Tools, such as provided by THREDDS [ER21], will use these attributes for extracting metadata from datasets, and exporting to Dublin Core, DIF, ADN, FGDC, ISO 19115 etc. metadata formats. In particular, this allows for the export of geospatial metadata in XML according to the ISO 19139 specification, which provides the XML implementation schema for ISO 19115. In the *"Metadata specification for the TROPOMI L1b products"* [RD9] a comprehensive description of these metadata models and how they are applied to the L1b products are given. Section 8 describes how the metadata is stored in the netCDF file, allowing extraction and exporting to different metadata formats.

7.2.1 NetCDF File Structure

The file format of the L1b products is structured using groups compliant with the netCDF-4 enhanced model. The group hierarchy is as follows ("/" indicating the root of the groups):

```
/
/global attributes
/MetadataGroup [1]
/MetadataGroup/ISOMetadataGroup [1]
/MetadataGroup/EOPMetadataGroup [1]
/MetadataGroup/ESAMetadataGroup [1]
/ProductGroup [1,*]
```

```
/ProductGroup/SensorModeGroup [1,*]
/ProductGroup/SensorModeGroup/ObservationsGroup [1]
/ProductGroup/SensorModeGroup/GeodataGroup [1]
/ProductGroup/SensorModeGroup/InstrumentGroup [1]
/ProductGroup/SensorModeGroup/ProcessorGroup [1]
/ProductGroup/SensorModeGroup/AttributesGroup [1]
```

In the above schema, for each group is indicated how many occurrences of the particular group are expected/allowed in the parent group ([1,*] meaning 1 or more).

This grouping has several benefits:

- Different metadata groups allow for extraction of metadata into XML documents conforming the different metadata specifications.
- ProductGroups allow the combination of observations made by different sensors into one netCDF file (i.e. Band_1 Radiance, Band_2 Radiance, . . .)
- SensorModeGroups allow the combination of observations made by the same sensor operating in different modes (i.e. standard mode, zoom mode, . . .)
- The various subgroups of the SensorModeGroup allow grouping of measurement data, location data, instrument data, processor data and other, simplifying the access to the relevant information depending on the intended use.
- The AttributesGroup consists of only attributes specific for this sensor mode.

In principle global attributes contain all product metadata. However, in some cases metadata might be specific to the sensor mode. This information is stored as attributes in the AttributesGroup under the SensorModeGroup.

7.2.2 Naming conventions

7.2.2.1 Groups

Group names are in upper case and consist of alphanumeric characters and underscores. Spaces are not allowed. The group names for the different groups are defined as follows:

MetadataGroup For all products fixed to: `METADATA`

ISOMetadataGroup For all products fixed to: `ISO_METADATA`

EOPMetadataGroup For all products fixed to: `EOP_METADATA`

ESAMetadataGroup For all products fixed to: `ESA_METADATA`

ProductGroup For radiance products one of the following:

`BAND1_RADIANCE | BAND2_RADIANCE | BAND3_RADIANCE | BAND4_RADIANCE | BAND5_RADIANCE | BAND6_RADIANCE | BAND7_RADIANCE | BAND8_RADIANCE`

For irradiance products one or more of the following:

`BAND1_IRRADIANCE | BAND2_IRRADIANCE | BAND3_IRRADIANCE | BAND4_IRRADIANCE | BAND5_IRRADIANCE | BAND6_IRRADIANCE | BAND7_IRRADIANCE | BAND8_IRRADIANCE`

SensorModeGroup For all products one of the following:

`STANDARD_MODE | SPECIAL_MODE_X` (where X = 0 . . . n and is just an index number)

There is one `STANDARD_MODE` group. This means that all measurements taken in the standard mode operation are combined even if the standard operation mode is interleaved with operations of the sensor in a special mode.

ObservationsGroup For all products fixed to: `OBSERVATIONS`

GeodataGroup For all products fixed to: `GEODATA`

InstrumentGroup For all products fixed to: `INSTRUMENT`

ProcessorGroup For all products fixed to: `PROCESSOR`

AttributesGroup For all products fixed to: `INFORMATION`

7.2.2.2 Variables, attributes and dimensions

All variables and dimensions are written in lower case and consist of alphanumeric characters and underscores. Spaces are not allowed.

Unless specified by CF Conventions or ACDD conventions, attributes are written in lower case and consist of alphanumeric characters and underscores. Spaces are not allowed.

7.2.3 Dimensions and coordinate variables

The spectral radiance measurements are collected as a function of the two dimensions (ground pixels across track and wavelengths) of the detector and of the scans. The corresponding dimensions describing the swath in the netCDF product are named: `ground_pixel`, `spectral_channel` and `scanline`, respectively. For reasons of interoperability the dimension time was added with a fixed size of unity as well as a one-element coordinate variable `time(time)` indicating the reference time of the measurements. This reference time is yyyy-mm-ddT00:00:00 UTC, where yyyy-mm-dd is the day on which the measurements of a particular data granule start. The `delta_time(scanline)` variable indicates the time difference with the reference time time(time). Thus combining the information of `time(time)` and `delta_time(scanline)` yields the measurement time for each scanline as UTC time.

Following the recommendations of the CF Conventions with respect to the ordering of dimensions having the interpretations of “date or time” (T), “height or depth” (Z), “latitude” (Y) or “longitude” (X), a logical ordering of the dimensions would be (`time, spectral_channel, scanline, ground_pixel`). However, performance tests have shown that given the preferred way of reading through the data, a relative order of (`time, scanline, ground_pixel, spectral_channel`) is preferable; this latter dimension ordering is therefore selected for the variables.

In case of a swath-type scanning pattern as used by TROPOMI, the `scanline` and `ground_pixel` dimensions cannot be referred to as latitude and longitude because they are on a different grid. However, latitude and longitude information can be stored in auxiliary coordinate variables (here: `latitude(time, scanline, ground_pixel)` and `longitude(time, scanline, ground_pixel)`), which are identified by the `coordinates` attribute. By using this convention, applications will be able to process the latitude and longitudes correctly, allowing, for instance, plotting swath-like measurements on a latitude, longitude grid.

One more dimension is defined in the radiance products: `ncorner`. The dimension `ncorner` has a fixed size of 4 and is used for specifying the corner coordinates of the individual ground pixels. The corner coordinates are specified by the `latitude_bounds(time, scanline, ground_pixel, ncorner)` and `longitude_bounds(time, scanline, ground_pixel, ncorner)` variables, which represent the boundaries of each pixel.

Because during the irradiance measurements the sensors are not imaging the Earth’s surface but are measuring the solar irradiance, `pixel` is the preferred name for the across-track dimension. Moreover, after correction for the sun elevation the individual irradiance measurements as function of `scanline` are averaged, which results in just one measurement.

Table 10 lists the typical size of the dimensions for different detectors and bands.

Detector	**UV**		**UVIS**		**NIR**		**SWIR**	
Band	1	2	3	4	5	6	7	8
`time`	1	1	1	1	1	1	1	1
`spectral_channel`	385	385	470	470	512	512	500	500
`scanline`	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited	unlimited
`ground_pixel (pixel)`	79	316	316	316	316	456	256	256

Table 10: NetCDF dimension sizes; the size of dimension `scanline` is UNLIMITED. A typical value for this size for a radiance product making observations at the day-side of the Earth is 3300. For irradiance products `scanline=1`.

7.2.4 Compression, checksum and chunk sizes

<TBD #1> Discussion on compression, checksum and chunking

7.3 L1b products

7.3.1 Radiance products

The following tables (Table 11 to Table 15) list all variables of the radiance products as they appear in the different groups. There is no difference between standard and near-real time products. A detailed description in CDL is provided in sections 8.5 to 8.46. The netCDF base types are defined in Table 39.

ObservationsGroup		
Variable	**Type**	**Description**
time	int	Reference time of the measurements. The reference time is set to yyyy-mm-ddT00:00:00 UTC, where yyyy-mm-dd is the day on which the measurements of a particular data granule start.
spectral_channel	int	Coordinate variable defining the indices in the spectral dimension
scanline	int	Coordinate variable defining the indices along track
ground_pixel	int	Coordinate variable defining the indices across track
delta_time	int	Time difference with time for each measurement
radiance	float	Measured spectral radiance for each spectral pixel
radiance_error	byte	Estimate of the systematic error (accuracy) of the measured spectral radiance (includes calibration and model errors).
radiance_noise	byte	Estimate of the statistical error (precision) of the measured spectral radiance (includes shot noise and read noise).
small_pixel_radiance	float(*)	Measured spectral radiance for the spectral channel dedicated for the small pixel measurements
quality_level	ubyte	Overall quality assessment information for each (spectral) pixel
spectral_channel_quality	ubyte	Quality assessment information for each (spectral) pixel
detector_row_qualification	ushort	Qualification flag indicating the detector row type or state
detector_column_qualification	ushort	Qualification flag indicating column type or state
measurement_quality	ushort	Overall quality information for a measurement
ground_pixel_quality	ubyte	Quality assessment information for each ground pixel

Table 11: NetCDF variables in the ObservationGroup for radiance products

<TBD #2> Consider to move dimension variables to SensorModeGroup

GeodataGroup		
Variable	**Type**	**Description**
latitude	float	Latitude of the center of each ground pixel on the WGS84 reference ellipsoid
latitude_bounds	float	The four latitude boundaries of each ground pixel.
longitude	float	Longitude of the center of each ground pixel on the WGS84 reference ellipsoid
longitude_bounds	float	The four longitude boundaries of each ground pixel.
satellite_orbit_phase	float	Relative offset (0.0 ... 1.0) of the measurement in the orbit
satellite_altitude	float	The altitude of the spacecraft relative to the WGS84 reference ellipsoid
satellite_latitude	float	Latitude of the spacecraft sub-satellite point on the WGS84 reference ellipsoid
satellite_longitude	float	Longitude of the spacecraft sub-satellite point on the WGS84 reference ellipsoid
viewing_azimuth_angle	float	Azimuth angle of the spacecraft measured from the ground pixel WGS84 reference ellipsoid.
viewing_zenith_angle	float	Zenith angle of the spacecraft measured from the ground pixel location on the WGS84 reference ellipsoid.
solar_azimuth_angle	float	Azimuth angle of the sun measured from the ground pixel location on the WGS84 ellipsoid.
solar_zenith_angle	float	Zenith angle of the sun measured from the ground pixel location on the WGS84 reference ellipsoid.
earth_sun_distance	float	Distance between the Earth and Sun

Table 12: NetCDF variables in the GeodataGroup for radiance products. [Note: Because of the nature of the information the variables latitude, longitude, latitude_bounds and longitude_bounds are placed in the GeodataGroup. However, current software applications might have problems to find the auxiliary coordinate variables (in this case latitude and longitude) listed by the coordinates attribute of a variable in the ObservationsGroup.]

InstrumentGroup		
Variable	**Type**	**Description**
processing_class	short	High level identification of the type of measurement, for example earth / radiance, sun / irradiance, WLS calibration, LED calibration, dark current / background, etc.
instrument_configuration	compound	Identifier (number) that identifies the (detailed) type of measurement and the configuration of the instrument
instrument_settings	compound	All fields that determine the instrument configuration and are relevant for data processing, like exposure tme, binning factors, co-addition period, gain settings, status of calibration unit, etc.
housekeeping_data	compound	Fields that describe scanline dependent instrument characteristics, like detector temperatures, etc.
binning_table	compound	Contains the binning configuration for all of the instrument configurations used in the group. Not present in SWIR products
nominal_wavelength	float	The nominal spectral wavelength for each cross track pixel as a function of the spectral channel.

Table 13: NetCDF variables in the InstrumentGroup for radiance products

<TBD #3> binning_table, column_flags and row_flags to be determined

ProcessorGroup		
Variable	**Type**	**Description**
sample_cycle	int	Index of cycle. During one sample cycle an integer number of scanlines is collected
sample_cycle_length	int	Length of sample_cycle

Table 14: NetCDF variables in the ProcessorGroup for radiance products

<TBD #4> Exact definition of ProcessorGroup variables

AttributesGroup		
Variable	**Type**	**Description**
number_of_measurements	attribute	Number of measurements

Table 15: NetCDF variables in the AttributesGroup for radiance products

7.3.2 Irradiance products

The following tables (Table 16 to Table20) list all variables of the irradiance products. A detailed description in CDL is provided in sections 8.5 to 8.46. The netCDF base types are defined in Table 39.

ObservationsGroup		
Variable	**Type**	**Description**
time	int	Reference time of the measurements. The reference time is set to yyyy-mm-ddT00:00:00 UTC, where yyyy-mm-dd is the day on which the measurements of a particular data granule start.
spectral_channel	int	Coordinate variable defining the indices in the spectral dimension
scanline	int	Coordinate variable defining the indices along track
pixel	int	Coordinate variable defining the indices across track
delta_time	int	Time difference with time for each measurement
irradiance	float	Measured spectral irradiance for each spectral pixel
irradiance_error	byte	Estimate of the systematic error (accuracy) of the measured spectral radiance (includes calibration and model errors).
irradiance_noise	byte	Estimate of the statistical error (precision) of the measured spectral irradiance (includes shot noise and read noise)
quality_level	ubyte	Overall quality assessment information for each (spectral) pixel
spectral_channel_quality	ubyte	Quality assessment information for each (spectral) pixel
detector_row_qualification	ushort	Qualification flag indicating the detector row type or state
detector_column_qualification	ushort	Qualification flag indicating column type or state
measurement_quality	ushort	Overall quality information for a measurement
calibrated_wavelength	float	Calibrated wavelength of each spectral pixel

Table 16: NetCDF variables in the ObservationGroup for irradiance products

GeodataGroup		
Variable	**Type**	**Description**
satellite_orbit_phase	float	Relative offset (0.0 ... 1.0) of the measurement in the orbit
satellite_altitude	float	The altitude of the spacecraft relative to the WGS84 reference ellipsoid
satellite_latitude	float	Latitude of the spacecraft sub-satellite point on the WGS84 reference ellipsoid
satellite_longitude	float	Longitude of the spacecraft sub-satellite point on the WGS84 reference ellipsoid
solar_azimuth_angle	float	Azimuth angle of the sun measured from the instrument
solar_elevation_angle	float	Elevation angle of the sun measured from the instrument.
earth_sun_distance	float	Distance between the Earth and Sun

Table 17: NetCDF variables in the GeodataGroup for irradiance products

<TBD #5> reference to ATBD description w.r.t. solar_azimuth_angle

InstrumentGroup		
Variable	**Type**	**Description**
processing_class	short	High level identification of the type of measurement, for example earth / radiance, sun / irradiance, WLS calibration, LED calibration, dark current / background, etc.
instrument_configuration	compound	Identifier (number) that identifies the (detailed) type of measurement and the configuration of the instrument
instrument_settings	compound	All fields that determine the instrument configuration and are relevant for data processing, like exposure tme, binning factors, co-addition period, gain settings, status of calibration unit, etc.
housekeeping_data	compound	Fields that describe scanline dependent instrument characteristics, like detector temperatures, etc.
binning_table	compound	Contains the binning configuration for all of the instrument configurations used in the group. Not present in SWIR products
nominal_wavelength	float	The nominal spectral wavelength for each cross track pixel as a function of the spectral channel.

Table 18: NetCDF variables in the InstrumentGroup for irradiance products

ProcessorGroup		
Variable	**Type**	**Description**
sample_cycle	int	Index of cycle. During one sample cycle an integer number of scanlines is collected
sample_cycle_length	int	Length of sample_cycle

Table 19: NetCDF variables in the ProcessorGroup for irradiance products

<TBD #6> Exact definition of ProcessorGroup variables

AttributesGroup		
Variable	**Type**	**Description**
number_of_measurements	attribute	Number of measurements

Table 20: NetCDF variables in the AttributesGroup for irradiance products

7.3.3 Calibration products

<TBD #7> Definition of calibration product

7.3.4 Engineering product

The engineering products are input for the calibration processors who will use these products for generating updates to the calibration key data and for generating trending and monitoring products. The L1b engineering product is only intended for calibration and monitoring purposes. All instrument information needed or relevant for L2 processing will be contained within the radiance and irradiance products. As such, the engineering product is expected to be used by experts investigating and troubleshooting instrument performance anomalies. For that reason, only a high level description of the product is provided here. However, this description together with the detailed information contained in the netCDF and the Command and Telemetry Handbook [RD16] will allow expert users to retrieve the relevant engineering data.

7.3.4.1 NetCDF File Structure

The engineering product has a different NetCDF file structure as the file structure for radiance and irradiance products described in section 7.2.1. However, except for the group names, all naming conventions described in section 7.2.2 apply. The file format of the L1b engineering product is structured using groups compliant with the netCDF-4 enhanced model. The group hierarchy is as follows ("/" indicating the root of the groups):

```
/
/DetectorGroup [4]
/DetectorGroup/BandGroup [2]
/DetectorGroup/DetectorHousekeepingGroup [1]
/MeasurementSetGroup [1]
/NominalHouseKeepingGroup/EventsGroup [1]
/NominalHouseKeepingGroup/FoldingMirrorsGroup [1]
/NominalHouseKeepingGroup/HeatersGroup [1]
/NominalHouseKeepingGroup/LEDInformationGroup [1]
/NominalHouseKeepingGroup/OBDHGroup [1]
/NominalHouseKeepingGroup/SoftwareConfigurationGroup [1]
/NominalHouseKeepingGroup/TemperaturesGroup [1]
/NominalHouseKeepingGroup/VersionInformationGroup [1]
/NominalHouseKeepingGroup/VoltagesGroup [1]
```

All groups in the schema listed above are always present in the netCDF file. The relation between detector type, detector number and bands can be found in Table 10. In the L0 product instrument parameters are available in engineering data packages. The L01b processor extracts all the parameters from these data packages and groups them in variables which are then stored in the netCDF engineering product. The variables are stored in different groups; the groups and the variables they contain are described in the following sections.

7.3.4.2 Groups

Group names are in upper case and consist of alphanumeric characters and underscores. Spaces are not allowed. The group names for the different groups are defined as follows:

DetectorGroup fixed to: `DETECTOR1` | `DETECTOR2` | `DETECTOR3` | `DETECTOR4`

BandGroup fixed to: `BAND1` | `BAND2` | `BAND3` | `BAND4` | `BAND5` | `BAND6` | `BAND7` | `BAND8`

DetectorHousekeepingGroup fixed to: `DETECTOR_HK`

MeasurementSetGroup fixed to: `MSMTSET_GRP`

NominalHouseKeepingGroup fixed to: `NOMINAL_HK`

EventsGroup fixed to: `EVENTS`

FoldingMirrorsGroup fixed to: FOLDING_MIRRORS

HeatersGroup fixed to: HEATERS

LEDInformationGroup fixed to LED_DATA

OBDHGroup fixed to OBDH_DATA

SoftwareConfigurationGroup fixed to SW_CFG

TemperaturesGroup fixed to TEMPERATURES

VersionInformationGroup fixed to VERSION_INFO

VoltagesGroup fixed to VOLTAGES

7.3.4.3 Group contents

The following tables (Table 21 to Table 36) list all variables in the engineering product as they appear in the different groups. A detailed description is outside the scope of this document.

DetectorGroup UVN detector		
Variable	**Type**	**Description**
afe_common_config	compound	Extracted AFE setting common for both bands on the detector
afe_reg_vals	compound	Raw AFE register values from which the AFE parameters are extracted
ft_table	compound	Frame Transfer synchronization parameters as stored in the DEM
timing	componud	Detector specific timing parameters. Partly extracted from ft_table parameters
heater_config	compound	Heater settings for the detector
misc	compound	Miscellaneous parameters for the detector that don't fit in other groups

Table 21: NetCDF variables in the DetectorHousekeepingGroup of the engineering product for UVN detectors (detector1 - detector3)

DetectorGroup SWIR detector		
Variable	**Type**	**Description**
ft_table	compound	Frame Transfer synchronization parameters as stored in the DEM
timing	componud	Detector specific timing parameters. Partly extracted from ft_table parameters
swir_settings	compound	Extracted detector settings which are valid for both bands read from the SWIR Detector

Table 22: NetCDF variables in the DetectorGroup of the engineering product for the SWIR detector (detector4)

BandGroup UVN detector		
Variable	**Type**	**Description**
readout_cfg	compound	Read-out settings for the band as used by the ISM.
afe_band_cfg	compound	Band specific settings extracted from the AFE registers.

Table 23: NetCDF variables in the BandGroup of the engineering product for the UVN detectors (detector1-detector3)

BandGroup SWIR detector		
Variable	**Type**	**Description**
readout_cfg	compound	Read-out settings for the band as used by the ISM.

Table 24: NetCDF variables in the BandGroup of the engineering product for the SWIR detector (detector4)

DetectorHousekeepingGroup UVN detector		
Variable	**Type**	**Description**
dem_cntrs	compound	DEM counter values for the detector
power_info	compound	Current and voltage values specific for the detector
stat_info	compound	Extracted status values specific for the detector
temperature_info	compound	Temperature values specific for the detector
version_info	compound	DEM firmware version information for the detector

Table 25: NetCDF variables in the DetectorHousekeepingGroup of the engineering product for the UVN detectors (detector1-detector3)

DetectorHousekeepingGroup SWIR detector		
Variable	**Type**	**Description**
adc_info	compound	Extracted current SWIR ADC values
dem_cntrs	compound	DEM counter values for the detector
err_cntrs	compound	SWIR specific error counters
power_info	compound	Current and voltage values specific for the detector
stat_info	compound	Extracted status values specific for the detector
temperature_info	compound	Temperature values specific for the detector
version_info	compound	DEM firmware version information for the detector
tmtc_info	compound	Extracted TMTC counter values

Table 26: NetCDF variables in the DetectorHousekeepingGroup of the engineering product for the SWIR detector (detector4)

MeasurementSetGroup		
Variable	**Type**	**Description**
msmt_set	compound	Measurement set information of all engineering data packages, like processing class, instrument configuration and selected DEM and ISM tables

Table 27: NetCDF variables in the MeasurementSetGroup of the engineering product

EventsGroup		
Variable	**Type**	**Description**
events	compound	General event information extracted from the housekeeping data
processing_events	compound	Processing event information extracted from the housekeeping data

Table 28: NetCDF variables in the EventsGroup of the engineering product

FoldingMirrorsGroup		
Variable	**Type**	**Description**
difm	compound	Status information about the folding mirror mechanism on the instrument
ffm	compound	Status information about the diffuser mechanism on the instrument

Table 29: NetCDF variables in the FoldingMirrorsGroup of the engineering product

HeatersGroup		
Variable	**Type**	**Description**
heater_data	compound	Settings and status information about the heaters on the instrument
peltier_data	compound	Settings and status information about the peltier elements on the instrument

Table 30: NetCDF variables in the HeatersGroup of the engineering product

LEDInformationGroup		
Variable	**Type**	**Description**
led_data	compound	Status and voltage information about the LEDs on the instrument

Table 31: NetCDF variables in the LEDInformationGroup of the engineering product

OBDHGroup		
Variable	**Type**	**Description**
obdh_data	compound	Onboard data handling data parameters

Table 32: NetCDF variables in the OBDHGroup of the engineering product

SoftwareConfigurationGroup		
Variable	**Type**	**Description**
params	compound	Software configuration parameters of the instrument.

Table 33: NetCDF variables in the SoftwareConfigurationGroup of the engineering product

TemperaturesGroup		
Variable	**Type**	**Description**
hires_temperatures	compound	Calculated temperatures of the high-resolution temperature sensors on the instrument
instr_temperatures	compound	Calculated temperatures of the instrument temperature sensor on the instrument
named_temperature	compound	Calculated temperatures of named sensors in the engineering data
reference_thermistors	compound	Calculated resistor values of the reference thermistors

Table 34: NetCDF variables in the TemperaturesGroup of the engineering product

VersionInformationGroup		
Variable	**Type**	**Description**
info	compound	Version information of onboard software of the instrument

Table 35: NetCDF variables in the VersionInformationGroup of the engineering product

VoltagesGroup		
Variable	**Type**	**Description**
detector1_voltages	compound	Voltages measured for detector1
detector2_voltages	compound	Voltages measured for detector2
detector3_voltages	compound	Voltages measured for detector3
detector4_voltages	compound	Voltages measured for detector4
instrument_voltages	compound	Instrument voltages

Table 36: NetCDF variables in the VoltagesGroup of the engineering product

8 TROPOMI L1b product specification

8.1 NetCDF4 global attributes

In the "Metadata specification for the TROPOMI L1b products" [RD9] it is discussed how metadata content can be provided by the use of global attributes, thereby facilitating the discovery and understanding of the dataset. The CF-Metadata conventions [RD13] and the Attribute Conventions for Dataset Discovery [ER20] recommend a comprehensive set of attributes to be included as metadata elements. However, for TROPOMI L1b products it was decided to create specific metadata groups in which INSPIRE (ISO), ESA EOP and ESA FFS related metadata information is stored. Many of the metadata attributes proposed by CF-Metadata Conventions and ACDD overlap with the ISO 19115-2 standard and hence the same information can be found in the metadata groups.

In view of the above, only a very limited set of metadata elements is included as global attributes. These attributes provide a convenient way to users of the data products to retrieve quickly some basic information. In Table 37 a list is presented of metadata items included as global attributes in the netCDF product file.
<TBD #8> Consider to included references attribute

Attribute	ISO mapping	Remark
`Conventions`		fixed: "CF-1.6"
`title`	MI_Metadata.identificationInfo. citation.title	
`summary`	MI_Metadata.identificationInfo. abstract	
`institution`	MI_Metadata.identificationInfo. pointOfContact.organisationName	
`time_coverage_start`	MI_Metadata.identificationInfo. extent.temporalElement.beginPosition	UTC time (start of measurements)
`time_coverage_end`	MI_Metadata.identificationInfo. extent.temporalElement.endPosition	UTC time (end of measurements)
`time_reference`		UTC time (reference time = "yyyy-mm-ddT00:00:00Z")
`orbit`		orbit number at which measurements of the data granule start

Table 37: Global attributes. Remark 1: UTC times are in expressed in the ISO 8601 format (i.e. YYYY-MM-DDThh:mm:ssZ). Remark 2: the values of `time_coverage_start` and `time_coverage_end` truncated to integer seconds appear in the filename of the product (see section 7.1.1.3). Remark 3: for the definition of the reference time see section 8.5.

8.2 Metadata specification

The netCDF file will have one metadata group (named METADATA) which is a container for specific metadata groups containing metadata information required to produce INSPIRE conformant [RD14], ESA EOP conformant [RD15] and ESA FFS conformant [AD6] XML formatted metadata records. These three specific metadata groups (see also [RD9]) named ISO_METADATA, EOP_METADATA and ESA_METADATA, are structured in subgroups containing only attributes.

The structure of the groups reflects the structure of the particular metadata model, i.e. the groups correspond largely with the major metadata objects of the model. Whenever applicable, the groups contain an attribute with name="objectType" with a value equal to the corresponding object (including namespace) from the metadata model. This approach follows the groups-of-groups approach suggested by [ER22]. In addition, the attributes containing the relevant metadata information are given the same name as the corresponding element of the metadata model.

Listing 1 and Listing 2 show examples of the structure of the ISO_METADATA group and the EOP_-METADATA group, respectively as present in the METADATA group in the netCDF file. This structure is shown using NcML. NcML is an XML representation of netCDF metadata and is similar to the netCDF CDL (network

Common data form Description Language). The subgroups (here left empty for better readability) have a similar structure containing attributes (with one attribute with name="objectType") and subgroups. A full example is provided in Annex D.

Listing 1: NcML representation of the attributes of the ISO_METADATA group. For better readability the subgroups *contact*, *identificationInfo*, *dataQualityInfo* and *acquisitionInformation* are left empty, as well as the metadata groups EOP_METADATA and ESA_METADATA.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2">
  <group name="METADATA">
    <group name="ISO_METADATA">
      <attribute name="objectType" value="gmi:MI_Metadata"/>
      <attribute name="gmd:fileIdentifier"
          value="urn:ogc:def:EOP:ESA:SENTINEL.S5P_TROP_L1B_RAD_BD1"/>
      <group name="gmd:language">
        <attribute name="objectType" value="gmd:LanguageCode"/>
        <attribute name="codeList" value="http://www.loc.gov/standards/iso639-2/"/>
        <attribute name="codeListValue" value="eng"/>
      </group>
      <group name="gmd:characterSet">
        <attribute name="objectType" value="gmd:MD_CharacterSetCode"/>
        <attribute name="codeList"
            value="http://www.isotc211.org/2005/resources/Codelist/
            gmxCodelists.xml#MD_CharacterSetCode"/>
        <attribute name="codeListValue" value="utf8"/>
      </group>
      <group name="gmd:hierarchyLevel">
        <attribute name="objectType" value="gmd:MD_ScopeCode"/>
        <attribute name="codeList"
            value="http://www.isotc211.org/2005/resources/Codelist/
            gmxCodelists.xml#MD_ScopeCode"/>
        <attribute name="codeListValue" value="series"/>
      </group>
      <attribute name="gmd:hierarchyLevelName" value="EO Product Collection"/>
      <group name="gmd:contact"/>
      <attribute name="gmd:dateStamp" value="2014-11-14"/>
      <attribute name="gmd:metadataStandardName" value="ISO 19115-2 Geographic
          Information - Metadata Part 2 Extensions for imagery and gridded data"/>
      <attribute name="gmd:metadataStandardVersion" value="ISO 19115-2:2009(E), S5P
          profile"/>
      <group name="gmd:identificationInfo"/>
      <group name="gmd:dataQualityInfo"/>
      <group name="gmi:acquisitionInformation"/>
    </group>
    <group name="EOP_METADATA"/>
    <group name="ESA_METADATA"/>
  </group>
</netcdf>
```

Listing 2: NcML representation of the attributes of the EOP_METADATA group. For better readability the subgroups *procedure*, *observedProperty*, *featureOfInterest*, *result* and *metadataProperty* are left empty, as well as the metadata groups ISO_METADATA and ESA_METADATA.

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2">
  <group name="METADATA">
    <group name="ISO_METADATA"/>
    <group name="EOP_METADATA">
```

```
      <attribute name="objectType" value="atm:EarthObservation"/>
      <attribute name="gml:id"
          value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
          _02_010203_20151204T093045.ID"/>
      <group name="om:phenomenonTime">
        <attribute name="objectType" value="gml:TimePeriod"/>
        <attribute name="gml:beginPosition" value="2015-11-14T11:45:11"/>
        <attribute name="gml:endPosition" value="2015-11-14T12:15:59"/>
      </group>
      <group name="om:resultTime">
        <attribute name="objectType" value="gml:TimeInstant"/>
        <attribute name="gml:timePosition" value="2015-11-16T19:54:00"/>
      </group>
      <group name="om:procedure"/>
      <group name="om:observedProperty"/>
      <group name="om:featureOfInterest"/>
      <group name="om:result"/>
      <group name="eop:metaDataProperty"/>
    </group>
    <group name="ESA_METADATA"/>
  </group>
</netcdf>
```

8.3 NetCDF4 variable attributes

Similar to global attributes providing metadata information of the complete dataset, variable attributes provide the means to attach ancillary data or metadata for each individual netCDF variable. The netCDF specification recommends some standard attributes that are proven to be useful. In addition, the CF-Conventions recommend the use of some extra attributes to annotate the variables with descriptive information.Table 38 presents an list of attributes that are used to describe the L1b variables.

Attribute	Description
ancillary_variables	Attribute to express relationship with other variables; For example, to relate instrument data with associated measures of uncertainty.
bounds	The name of the variable that contains the vertices of the cell boundaries. Used to relate the variable to a coordinate variable.
coordinates	Indicates the spatiotemporal coordinate variables that are needed to geo-locate the data
comment	Miscellaneous information about the variable or methods used to produce it
flag_meanings	The flag_meanings attribute is a string whose value is a blank separated list of descriptive words or phrases, one for each flag value.
flag_values	The flag_values attribute is the same type as the variable to which it is attached, and contains a list of the possible flag values
long_name	A long descriptive name describing the content of the variable
standard_name	A standardized name describing the content of the variable
units	A character string that specifies the units used for the variable's data (required for all variables that represent dimensional quantities, except for boundary variables)
valid_max	The maximum valid value for the variable
valid_min	The minimum valid value for the variable
_FillValue	The FillValue attribute specifies the fill value used for missing or undefined data

Table 38: Description of variable attributes

8.4 Fill values

The CF convention recommends to use the _FillValue attribute (or to use the default values) to assign a specific value to NetCDF variables in case of undefined or missing data. The `_FillValue` depends on the data type of the variable. The following table (Table 39) lists the values used for the various base data types. In the sections hereafter, the `_FillValue` attribute will only be present in de CDL descriptions if it is different from the default value.

	Type	Storage	_FillValue
	byte	8-bit signed integer	-127
	ubyte	8-bit unsigned integer	255
	short	16-bit signed integer	-32767
	ushort	16-bit unsigned integer	65535
	int	32-bit signed integer	-2147483647
	float	32-bit floating point	9.9692099683868690e+36 (hex: 0x1.ep+122)
	double	64-bit floating point	9.9692099683868690e+36 (hex: 0x1.ep+122)
	float(*)	32-bit floating point(*)	9.9692099683868690e+36 (hex: 0x1.ep+122)

Table 39: NetCDF type definitions and fill values. Remark 1: The base type for a VLEN type (Variable Length Array) is indicated as type(*), i.e. float(*), short(*), etc. Remark 2: In order to avoid rounding errors, it is recommended to programmers to use the hexadecimal notation when specifying the above fill values for float and double types.

8.5 Variable: `time`

The variable `time(time)` is the reference time of the measurements. The reference time is set to yyyy-mm-ddT00:00:00 UTC, where yyyy-mm-dd is the day on which the measurements of a particular data granule start. The `delta_time(scanline)` variable (see section 8.6) indicates the time difference with the reference time `time(time)`. Thus combining the information of `time(time)` and `delta_time(scanline)` yields the measurement time for each scanline as UTC time.

The reference `time(time)` corresponds to the global attribute `time_reference` which is an UTC time specified as an ISO 8601 date.

	Variable	Storage type	Units
	`time`	int	seconds

CDL	`int time(time) ;`
	`time:long_name = "reference start time of measurement" ;`
	`time:standard_name = "time" ;`
	`time:units = "seconds since 2010-01-01 00:00:00" ;`		

Remarks	The UTC time defined by this variable time corresponds to the global attribute `time_reference`, which is a UTC time specified as an ISO 8601 (i.e. YYYY-MM-DDThh:mm:ssZ).		

Table 40: CDL definition `time` variable

8.6 Variable: `delta_time`

The `delta_time(scanline)` variable indicates the time difference with the reference time `time(time)` (see section 8.5). Thus combining the information of `time(time)` and `delta_time(scanline)` yields the measurement time for each scanline as UTC time. The UTC time derived for the first scanline corresponds to the global attribute `time_coverage_start`. However, the UTC time derived for the last scanline does not correspond to global attribute `time_coverage_end`. One scanline measurement is the result of adding independent measurements during one co-addition period. The time attributed to the scanline measurement is equal to the measurement time of the first sample in this co-addition. It is the measurement time of the last sample in the co-addition period of the last scanline that corresponds to `time_coverage_end`.

	Variable	Storage type	Units
	delta_time	int	ms

CDL	`int delta_time(time,scanline) ;`
	`delta_time:long_name = "offset from the reference start time of measurement" ;`
	`delta_time:units = "ms" ;`		

Remarks			

Table 41: CDL definition `delta_time` variable

8.7 Variable: `ground_pixel`

The coordinate variable `ground_pixel` refers to the across-track dimension of the measurement. The spectral radiance measurements are collected as a function of the two-dimensions (ground pixels across track and wavelengths), of the detector and of the scans. The corresponding dimensions describing the swath in the netCDF product are named: `ground_pixel`, `spectral_channel` and `scanline`, respectively.

	Variable	Storage type	Units
	ground_pixel	int	none

CDL	`int ground_pixel(ground_pixel) ;`
	`ground_pixel:long_name = "across track dimension index" ;`
	`ground_pixel:units = "1" ;`
	`ground_pixel:comment = "This dimension variable defines the indices across track; index starts at 0" ;`		

Remarks	Coordinate variable; The `ground_pixel` ordering is from west to east, i.e. a higher index corresponds to a higher longitude value during the ascending part of the orbit.		

Table 42: CDL definition `ground_pixel` variable

8.8 Variable: `pixel`

The coordinate variable `pixel` refers to the across-track dimension of the measurement. Because during the irradiance measurements the sensors are not imaging the Earth's surface but are measuring the solar irradiance, `pixel` is the preferred name (rather than `ground_pixel`) for the across-track dimension.

	Variable	Storage type	Units
	pixel	int	none

CDL	`int pixel(pixel) ;`
	`pixel:long_name = "across track dimension index" ;`
	`pixel:units = "1" ;`
	`pixel:comment = "This dimension variable defines the indices across track; index starts at 0" ;`		

Remarks	Coordinate variable. The `pixel` ordering corresponds to the `ground_pixel` order in the radiance products, which is from west to east, i.e. a higher index in corresponds to a higher longitude value during the ascending part of the orbit		

Table 43: CDL definition `pixel` variable

8.9 Variable: `scanline`

The coordinate variable `scanline` refers to the along-track dimension of the measurement. Scanline numbering starts a 0 for each product. (Thus: the scanline value of 0 is not related to a 'fixed' time but to the first measurement in the product.)

	Variable	Storage type	Units
	scanline	int	none

CDL	`int scanline(scanline) ;`
	`scanline:long_name = "along track dimension index" ;`
	`scanline:units = "1" ;`
	`scanline:comment = "This dimension variable defines the indices along track; index starts at 0" ;`		

Remarks	Coordinate variable. The scanlines are time-ordered; meaning that "earlier" measurements come before "later" measurements		

Table 44: CDL definition `scanline` variable

8.10 Variable: `spectral_channel`

	Variable	Storage type	Units
	spectral_channel	int	none

CDL	`int spectral_channel(spectral_channel) ;`
	`spectral_channel:long_name = "wavelength dimension index" ;`
	`spectral_channel:units = "1" ;`
	`spectral_channel:comment = "This dimension variable defines the indices spectral dimension; index starts at 0" ;`		

Remarks	Coordinate variable; The spectral channels are ordered by increasing wavelength, i.e. a higher index corresponds to a higher wavelength value.		

Table 45: CDL definition `spectral_channel` variable

8.11 Variable: `radiance`

TROPOMI measures the light radiated from and reflected by the Earth's surface and atmosphere in a given direction. The *spectral radiance* is a measure of the rate of the energy received per unit area an per unit of the solid angle as a function of wavelength and is expressed in SI units W.m^{-2}.nm^{-1}.sr^{-1}. Because TROPOMI actually measures the rate of photons per unit area and the exact wavelength is not known the *spectral photon radiance* is provided in the L1b product. The spectral photon radiance is expressed with SI units mol.s^{-1}.m^{-2}.nm^{-1}.sr^{-1} using the amount of photons. [2] In addition, the spectral photon radiance provided is normalized to the Earth-Sun distance of 1AU. [3] If the Earth spectral radiance is denoted by S_{earth}, the wavelength by λ and the Earth-Sun distance by R, then the Earth spectral radiance normalized at 1AU is given by:

$$S_{\text{earth}}(R_{\text{AU}},\lambda) = \left(\frac{R}{R_{\text{AU}}}\right)^2 S_{\text{earth}}(R,\lambda)\ , \tag{1}$$

where R_{AU} is the Earth-Sun distance equal to 1AU. Similarly, the spectral photon radiance is normalized using the factor $\left(\frac{R}{R_{\text{AU}}}\right)^2$.

[2] 1 Mole (unit symbol *mol*) corresponds to Avogadro's number N_A and is equal to 6.02214129.10^{23} photons or N_A = 6.02214129.10^{23} mol^{-1}.
[3] 1 Astronomical Unit (AU) =149,597,870,700 meters

	Variable	Storage type	Units
	radiance	float	mol.s^{-1}.m^{-2}.nm^{-1}.sr^{-1}
CDL	float radiance(time,scanline,ground_pixel,spectral_channel) ; radiance:long_name = "spectral photon radiance" ; radiance:units = "mol.s-1.m-2.nm-1.sr-1" ; radiance:coordinates = "longitude latitude" ; radiance:ancillary_variables = "radiance_noise radiance_error quality_level spectral_channel_quality ground_pixel_quality" ;		
Remarks	There is no standard_name for spectral photon radiance as measured by sensors on board satellites. In line with the standard_name for radiance that has been suggested by the cf-satellite user community on the Unidata mailing list, toa_outgoing_spectral_photon_radiance is suggested here.		

Table 46: CDL definition radiance variable

8.12 Variable: radiance_noise

The radiance noise (and similarly the error and the irradiance noise and error) is represented as a 10 times the base-10 logarithmic value of the ratio between the radiance and the random error. Given the current rough indications of these errors the representation of the errors in dB is assumed to be accurate and precise. Using a byte type has a considerable contribution as to limiting the final product file size.
<TBD #9> Discussion on precision of (ir)radiance error and noise

	Variable	Storage type	Units
	radiance_noise	byte	none
CDL	byte radiance_noise(time,scanline,ground_pixel,spectral_channel) ; radiance_noise:long_name = "spectral photon radiance noise, one standard deviation" ; radiance_noise:units = "1" ; radiance_noise:coordinates = "longitude latitude" ; radiance_noise:comment = "The radiance_noise is a measure for the one standard deviation random error of the radiance measurement; it is expressed as 10 time the base-10 logarithmic value of the ratio between the radiance and the random error." ;		
Remarks			

Table 47: CDL definition radiance_noise variable

8.13 Variable: radiance_error

	Variable	Storage type	Units
	radiance_error	byte	none
CDL	byte radiance_error(time,scanline,ground_pixel,spectral_channel) ; radiance_error:long_name = "spectral photon radiance error, one standard deviation" ; radiance_error:units = "1" ; radiance_error:coordinates = "longitude latitude" ; radiance_error:comment = "The radiance_error is a measure for the one standard deviation error of the bias of the radiance measurement; it is expressed as 10 time the base-10 logarithmic value of the ratio between the radiance and the estimation error." ;		
Remarks			

Table 48: CDL definition radiance_error variable

8.14 Variable: irradiance

Every 15 orbits - approximately once every calendar day - TROPOMI will be commanded to perform a solar irradiance measurement. Irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface. Similar to the spectral radiance, the *spectral irradiance* is the irradiance as function of wavelength. The SI units of spectral irradiance are W.m^{-2}.nm^{-1}. However, like the case of the radiance variable, the L1b product provides the *spectral photon irradiance* with SI units mol.s^{-1}.m^{-2}.nm^{-1}. Also the spectral photon irradiance is normalized to the Earth-Sun distance of 1 AU by applying a factor $\left(\frac{R}{R_{\mathrm{AU}}}\right)^2$ (see Equation 1).

	Variable	Storage type	Units
	irradiance	float	mol.s^{-1}.m^{-2}.nm^{-1}
CDL	float irradiance(time,scanline,pixel,spectral_channel) ; irradiance:long_name = "spectral photon irradiance" ; irradiance:units = "mol.s-1.m-2.nm-1" ; irradiance:ancillary_variables = "irradiance_noise irradiance_error quality_level spectral_channel_quality" ;		
Remarks	There is no standard_name for spectral photon irradiance as measured by sensors on board satellites. In line with the standard_name for irradiance that has been suggested by the cf-satellite user community on the Unidata mailing list, toa_spectral_photon_irradiance is suggested here.		

Table 49: CDL definition irradiance variable

8.15 Variable: irradiance_noise

	Variable	Storage type	Units
	irradiance_noise	byte	none

CDL

```
byte irradiance_noise(time,scanline,pixel,spectral_channel) ;
irradiance_noise:long_name = "spectral photon irradiance noise, one
standard deviation" ;
irradiance_noise:units = "1" ;
irradiance_noise:coordinates = "longitude latitude" ;
irradiance_noise:comment = "The irradiance_noise is a measure for the
one standard deviation random error of the irradiance measurement; it is
expressed as 10 time the base-10 logarithmic value of the ratio between the
irradiance and the random error." ;
```

Remarks

Table 50: CDL definition irradiance_noise variable

8.16 Variable: irradiance_error

	Variable	Storage type	Units
	irradiance_error	byte	none

CDL

```
byte irradiance_error(time,scanline,pixel,spectral_channel) ;
irradiance_error:long_name = "spectral irradiance noise" ;
irradiance_error:units = "1" ;
irradiance_error:coordinates = "longitude latitude" ;
irradiance_error:comment = "The irradiance_error is a measure for the one
standard deviation error of the bias of the irradiance measurement; it is
expressed as 10 time the base-10 logarithmic value of the ratio between the
irradiance and the estimation error." ;
```

Remarks

Table 51: CDL definition irradiance_error variable

8.17 Variable: small_pixel_radiance

One configurable detector pixel, in every row, for both detector output chains, i.e., two columns per detector, is not co-added and is stored separately for every exposure/co-addition of an image. The data for these 'small-pixel columns' are included in the science data and provide information on a higher spatial resolution than the data for other columns, which may be useful for certain studies. Thus for a given wavelength, the small_pixel_-radiance is the measurement of the spectral photon radiance expressed with SI units mol.s^{-1}.m^{-2}.nm^{-1}.sr^{-1}. The small_pixel_radiance is normalized to the Earth-Sun distance of 1 AU by applying a factor $\left(\frac{R}{R_{\mathrm{AU}}}\right)^2$ (see Equation 1).

	Variable	Storage type	Units
	small_pixel_radiance	float(*)	mol.s^{-1}.m^{-2}.nm^{-1}.sr^{-1}

CDL

```
types: float(*) small_pixel_radiance_type ;
small_pixel_radiance_type small_pixel_radiance(time,scanline,ground_pixel)
;
small_pixel_radiance:long_name = "small pixel photon radiance" ;
small_pixel_radiance:standard_name = "toa_outgoing_spectral_radiance" ;
small_pixel_radiance:units = "mol.s-1.m-2.nm-1.sr-1" ;
small_pixel_radiance:_FillValue = 0x1.ep+122 ;
small_pixel_radiance:coordinates = "longitude latitude" ;
```

Remarks small_pixel_type is a netCDF VLEN type

There is no standard_name for photon radiance as measured by sensors on board satellites. In line with the standard_name for radiance that has been suggested by the cf-satellite user community on the Unidata mailing list, toa_outgoing_spectral_photon_radiance is suggested here.

Table 52: CDL definition small_pixel_radiance variable

8.18 Variable: spectral_channel_quality

	Variable	Storage type	Units
	spectral_channel_quality	ubyte	none

CDL

```
ubyte spectral_channel_quality(time,scanline,ground_pixel,spectral_channel)
;
spectral_channel_quality:long_name = "spectral channel quality flag" ;
spectral_channel_quality:valid_min = 0 ;
spectral_channel_quality:valid_max = 254 ;
spectral_channel_quality:coordinates = "longitude latitude" ;
spectral_channel_quality:flag_values = 0UB, 1UB, 2UB, 8UB, 16UB, 32UB, 64UB,
128UB ;
spectral_channel_quality:flag_meanings = no_error, missing, bad_pixel,
processing_error, saturated, transient, rts, underflow ;
```

Remarks

Table 53: CDL definition spectral_channel_quality variable

8.19 Variable: ground_pixel_quality

	Variable	Storage type	Units
	ground_pixel_quality	ubyte	none
CDL	ubyte ground_pixel_quality(time,scanline,ground_pixel) ; ground_pixel_quality:long_name = "ground pixel quality flag" ; ground_pixel_quality:valid_min = 0 ; ground_pixel_quality:valid_max = 254 ; ground_pixel_quality:coordinates = "longitude latitude" ; ground_pixel_quality:flag_values = 0UB, 1UB, 2UB, 4UB, 8UB, 16UB ; ground_pixel_quality:flag_meanings = no_error, solar_eclipse, sun_glint_- possible, descending, night, geo_boundary_crossing, geolocation_error ;		
Remarks			

Table 54: CDL definition ground_pixel_quality variable

8.20 Variable: quality_level

The L1b variable quality_level is used to provide an overall indication of L1b data quality. Typically, to assign a quality level to a data product, *Quality Indicators (QIs)* are needed, in particular at each stage of the data processing chain - from collection and processing to delivery. A QI should provide sufficient information to allow all users to evaluate a product's suitability for their particular application. These QIs are provided to the users in the variable spectral_channel_quality (covering e.g. transient) and the variable ground_pixel_quality (covering e.g. solar eclipse). A QI is stored in a binary format, representing an on/off mode. Whenever a bit for a specific QI is set, this QI negatively influenced the determination of the quality_level.

The value for the overall quality is obtained by multiplying the quality indicators (ranging from 0 to 1) of the individual algorithms applied in the L01b processing chain. This product is then multiplied by hundred. Thus the maximum quality level is equal to 100; each processing algorithm might introduce a degradation which ultimately can result in the worst quality level equal to 0. However the automated quality assurance functionality of the L01b processor provides more detailed information on each QI (e.g. type of processor error or cause of saturation). A dedicated variable aqa is identified for the storage of detailed QI information.
<TBD #10> Detailed quality indicator information to be provided by the L01b processor.

	Variable	Storage type	Units
	quality_level	ubyte	none
CDL	ubyte quality_level(time,scanline,ground_pixel,spectral_channel) ; quality_level:long_name = "qualiy level of spectral channel" ; quality_level:valid_min = 0 ; quality_level:valid_max = 100 ; quality_level:coordinates = "longitude latitude" ;		
Remarks			

Table 55: CDL definition quality_level variable

8.21 Variable: `measurement_quality`

	Variable	Storage type	Units
	measurement_quality	ushort	none

CDL

```
ushort measurement_quality(time,scanline) ;
measurement_quality:long_name = "measurement quality flag" ;
measurement_quality:valid_min = 0 ;
measurement_quality:valid_max = 65534 ;
measurement_quality:coordinates = "longitude latitude" ;
measurement_quality:flag_values = 0UB, 1UB, 16UB, 32UB, 256UB ;
measurement_quality:flag_meanings = no_error, proc_skipped, saa,
spacecraft_manoeuvre, irr_out_of_range ;
```

Remarks Extended description:

- no_error: No measurement qualification
- proc_skipped: One or more processing steps (algorithms) where skipped
- Measurement was obtained while spacecraft was in South Atlantic Anomaly
- Measurement was obtained during spacecraft manoeuvre
- Measurement outside nominal elevation / azimuth range

Table 56: CDL definition `measurement_quality` variable

8.22 Variable: `detector_row_qualification`

Variable	Storage type	Units
`detector_row_qualification`	ushort	none

CDL

```
ushort detector_row_qualification(time,scanline,ground_pixel) ;
detector_row_qualification:long_name = "Detector row qualification flags" ;
detector_row_qualification:valid_min = 0 ;
detector_row_qualification:valid_max = 65534 ;
detector_row_qualification:flag_values = 0UB, 1UB, 2UB, 4UB, 8UB, 16UB,
256UB, 4096UB, 8192UB ;
detector_row_qualification:flag_meanings = no_qualification, uvn_ror,
uvn_dump, uvn_covered, uvn_overscan, uvn_higain, swir_reference, gen_-
transistion, gen_non_illuminated ;
detector_row_qualification:comment = "Qualification flag indicating row
type or state" ;
```

Remarks Extended description:

- no_qualification: No row qualification
- uvn_ror: UVN detector specific, row is read-out register (ROR)
- uvn_dump: UVN detector specific, row is read using dump gate setting
- uvn_covered: UVN detector specific, row is covered on detector
- uvn_overscan: UVN detector specific, over-scan row
- uvn_higain: UVN detector specific, row is read using high gain output
- swir_reference: SWIR detector specific, row is reference line
- Row is transition row on detector
- Row is not illuminated by spectrometer output

Table 57: CDL definition `detector_row_qualification` variable

8.23 Variable: detector_column_qualification

Variable	Storage type	Units
detector_column_qualification	ushort	none

CDL

```
ushort detector_column_qualification(time,scanline,spectral_channel) ;
detector_column_qualification:long_name = "Detector column qualification
flags" ;
detector_column_qualification:valid_min = 0 ;
detector_column_qualification:valid_max = 65534 ;
detector_column_qualification:flag_values = 0UB, 1UB, 16UB, 32UB, 64UB,
256UB, 512UB, 1024UB, 2048UB ;
detector_column_qualification:flag_meanings = no_qualification, skipped,
uvn_odd, uvn_prepost, uvn_overscan, swir_adc0, swir_adc1, swir_adc2, swir_-
adc3 ;
detector_column_qualification:comment = "Qualification flag indicating
column indicating column type or state" ;
```

Remarks Extended description:

- no_qualification: No column qualification
- skipped: Column was not read and therefore contains fill values
- uvn_odd: UVN detector specific, pixels in the column took the odd ADC path
- uvn_prepost: UVN detector specific, pixels in the column are pre- or post-scan pixels
- uvn_overscan: UVN detector specific, column is an over-scan column
- swir_adc0: SWIR detector specific, pixels in the column used ADC0
- swir_adc1: SWIR detector specific, pixels in the column used ADC1
- swir_adc2: SWIR detector specific, pixels in the column used ADC2
- swir_adc3: SWIR detector specific, pixels in the column used ADC3

Table 58: CDL definition detector_column_qualification variable

8.24 Variable: calibrated_wavelength

The nominal_wavelength (section 8.44) provides for each ground pixel the wavelength measured by a spectral channel and is defined by the design parameters of the instrument. The wavelength values as provided by the nominal_wavelength are based on the Calibration Key Data (CKD) which are input to the L01b processing (section 5).

During the measurements the actual measured wavelength will vary from the nominal one and a calibration step is required to correct for this effect. For radiance products this calibration is applied as part of the L2 processing, because it involves atmospheric corrections which are only available at that product level. Therefore, the calibrated_wavelength is not part of the L1b radiance product.

For the L1b irradiance products the calibrated_wavelength is available. As part of the L01b processing the spectral information obtained from the irradiance measurements is compared with a reference solar spectrum. From this comparison a calibrated set of wavelengths is derived which provides a per pixel best estimate for the wavelength actually measured by each individual spectral channel.

	Variable	Storage type	Units
	calibrated_wavelength	float	nm
CDL	float calibrated_wavelength(time,pixel,spectral_channel) ; calibrated_wavelength:long_name = "spectral channel nominal wavelength" ; calibrated_wavelength:standard_name = "radiation wavelength" ; calibrated_wavelength:units = "nm" ; calibrated_wavelength:valid_min = 270.f ; calibrated_wavelength:valid_max = 310.f ;		
Remarks	The calibrated_wavelength provides for each pixel the wavelength measured by a spectral channel and is defined by the design parameters of the instrument. The values mentioned for valid_min and valid_max apply to the Band1 product and serve as an example. The valid values for all products are listed in Table 1 in section 4.2		

Table 59: CDL definition calibrated_wavelength variable

8.25 Variable: latitude

	Variable	Storage type	Units
	latitude	float	degrees north
CDL	float latitude(time,scanline,ground_pixel) ; latitude:long_name = "pixel center latitude" ; latitude:standard_name = "latitude" ; latitude:units = "degrees_north" ; latitude:valid_min = -90.f ; latitude:valid_max = 90.f ; latitude:bounds = "latitude_bounds" ;		
Remarks	Latitude, longitude coordinates for the ground pixel center and the ground pixel corners are calculated at the WGS84 ellipsoid. In principle, the information provided in the GeodataGroup allows to calculate these coordinates at arbitrary altitudes.		

Table 60: CDL definition latitude variable

8.26 Variable: longitude

	Variable	Storage type	Units
	longitude	float	degrees east
CDL	float longitude(time,scanline,ground_pixel) ; longitude:long_name = "pixel center longitude" ; longitude:standard_name = "longitude" ; longitude:units = "degrees_east" ; longitude:valid_min = -180.f ; longitude:valid_max = 180.f ; longitude:bounds = "longitude_bounds" ;		
Remarks	Latitude, longitude coordinates for the ground pixel center and the ground pixel corners are calculated at the WGS84 ellipsoid. In principle, the information provided in the GeodataGroup allows to calculate these coordinates at arbitrary altitudes.		

Table 61: CDL definition longitude variable

8.27 Variable: `latitude_bounds`

The four corner points of the ground pixels are calculated as an interpolation between the centre coordinates (`longitude, latitude`) of adjacent pixels and lines. The variable `latitude_bounds` provides the latitude value of these corner points.
<TBD #11> Consider to use L2 figure explaining ncorner

	Variable	Storage type	Units
	`latitude_bounds`	float	none
CDL	`float latitude_bounds(time,scanline,ground_pixel,ncorner) ;`		
Remarks	CF-Convention: Since a boundary variable is considered to be part of a coordinate variable's metadata, it is not necessary to provide it with attributes such as `long_name` and `units`. Using a right-handed coordinate system, the ordering of the bounds is anti-clockwise on the longitude-latitude surface seen from above. Latitude, longitude coordinates for the ground pixel center and the ground pixel corners are calculated at the WGS84 ellipsoid. In principle, the information provided in the GeodataGroup allows to calculate these coordinates at arbitrary altitudes.		

Table 62: CDL definition `latitude_bounds` variable

8.28 Variable: `longitude_bounds`

The four corner points of the ground pixels are calculated as an interpolation between the centre coordinates (`longitude, latitude`) of adjacent pixels and lines. The variable `longitude_bounds` provides the longitude value of these corner points.

	Variable	Storage type	Units
	`longitude_bounds`	float	none
CDL	`float longitude_bounds(time,scanline,ground_pixel,ncorner) ;`		
Remarks	CF-Convention: Since a boundary variable is considered to be part of a coordinate variable's metadata, it is not necessary to provide it with attributes such as `long_name` and `units`. Using a right-handed coordinate system, the ordering of the bounds is anti-clockwise on the longitude-latitude surface seen from above. Latitude, longitude coordinates for the ground pixel center and the ground pixel corners are calculated at the WGS84 ellipsoid. In principle, the information provided in the GeodataGroup allows to calculate these coordinates at arbitrary altitudes.		

Table 63: CDL definition `longitude_bounds` variable

8.29 Variable: solar_zenith_angle

	Variable	Storage type	Units
	solar_zenith_angle	float	degree

CDL

```
float solar_zenith_angle(time,scanline,ground_pixel) ;
solar_zenith_angle:long_name = "solar zenith angle" ;
solar_zenith_angle:standard_name = "solar_zenith_angle" ;
solar_zenith_angle:units = "degree" ;
solar_zenith_angle:valid_min = 0.f ;
solar_zenith_angle:valid_max = 180.f ;
solar_zenith_angle:coordinates = "longitude latitude" ;
solar_zenith_angle:comment = "Solar zenith angle at the ground pixel
location on the reference ellipsoid.  Angle is measured away from the
vertical.  ESA definition of day side:  SZA less the 92 degrees" ;
```

Remarks

Table 64: CDL definition solar_zenith_angle variable

8.30 Variable: solar_elevation_angle

	Variable	Storage type	Units
	solar_elevation_angle	float	degree

CDL

```
float solar_elevation_angle(time,scanline) ;
solar_elevation_angle:long_name = "solar elevation angle" ;
solar_elevation_angle:units = "degree" ;
solar_elevation_angle:valid_min = 0.f ;
solar_elevation_angle:valid_max = 180.f ;
solar_elevation_angle:comment = "Solar elevation angle measured from the
instrument.  Angle is measured away from the vertical." ;
```

Remarks This variable is only present in the irradiance product

Table 65: CDL definition solar_elevation_angle variable

8.31 Variable: solar_azimuth_angle

The solar_azimuth_angle is defined differently for radiance and irradiance products.

8.31.1 Radiance product: solar_azimuth_angle

	Variable	Storage type	Units
	solar_azimuth_angle	float	degree

CDL

```
float solar_azimuth_angle(time,scanline,ground_pixel) ;
solar_azimuth_angle:long_name = "solar azimuth angle" ;
solar_azimuth_angle:standard_name = "solar_azimuth_angle" ;
solar_azimuth_angle:units = "degree" ;
solar_azimuth_angle:valid_min = 0.f ;
solar_azimuth_angle:valid_max = 360.f ;
solar_azimuth_angle:coordinates = "longitude latitude" ;
solar_azimuth_angle:comment = "Solar azimuth angle at the ground pixel
location on the reference ellipsoid.  Angle is measured clockwise from the
North (East = 90, South = 180, West = 270)" ;
```

Remarks

Table 66: CDL definition solar_azimuth_angle variable

8.31.2 Irradiance product: solar_azimuth_angle

	Variable	Storage type	Units
	solar_azimuth_angle	float	degree

CDL

```
float solar_azimuth_angle(time,scanline) ;
solar_azimuth_angle:long_name = "solar azimuth angle" ;
solar_azimuth_angle:standard_name = "solar_azimuth_angle" ;
solar_azimuth_angle:units = "degree" ;
solar_azimuth_angle:valid_min = 0.f ;
solar_azimuth_angle:valid_max = 360.f ;
solar_azimuth_angle:comment = "Azimuth angle of the sun measured from the
instrument" ;
```

Remarks

Table 67: CDL definition solar_azimuth_angle variable

8.32 Variable: viewing_zenith_angle

	Variable	Storage type	Units
	viewing_zenith_angle	float	degree
CDL	float viewing_zenith_angle(time,scanline,ground_pixel) ; viewing_zenith_angle:long_name = "viewing zenith angle" ; viewing_zenith_angle:standard_name = "platform_zenith_angle" ; viewing_zenith_angle:units = "degree" ; viewing_zenith_angle:valid_min = 0.f ; viewing_zenith_angle:valid_max = 180.f ; viewing_zenith_angle:coordinates = "longitude latitude" ; viewing_zenith_angle:comment = "Zenith angle of the satellite at the ground pixel location on the reference ellipsoid. Angle is measured away from the vertical." ;		
Remarks			

Table 68: CDL definition viewing_zenith_angle variable

8.33 Variable: viewing_azimuth_angle

	Variable	Storage type	Units
	viewing_azimuth_angle	float	degree
CDL	float viewing_azimuth_angle(time,scanline,ground_pixel) ; viewing_azimuth_angle:long_name = "viewing azimuth angle" ; viewing_azimuth_angle:units = "degree" ; viewing_azimuth_angle:valid_min = 0.f ; viewing_azimuth_angle:valid_max = 360.f ; viewing_azimuth_angle:coordinates = "longitude latitude" ; viewing_azimuth_angle:comment = "Azimuth angle of the satellite at the ground pixel location on the reference ellipsoid. Angle is measured clockwise from the North (East = 90, South = 180, West = 270)" ;		
Remarks			

Table 69: CDL definition viewing_azimuth_angle variable

8.34 Variable: satellite_latitude

	Variable	Storage type	Units
	satellite_latitude	float	degrees north
CDL	float satellite_latitude(time,scanline) ; satellite_latitude:long_name = "sub-satellite latitude" ; satellite_latitude:units = "degrees_north" ; satellite_latitude:valid_min = -90.f ; satellite_latitude:valid_max = 90.f ;		
Remarks			

Table 70: CDL definition satellite_latitude variable

8.35 Variable: satellite_longitude

	Variable	Storage type	Units
	satellite_longitude	float	degrees east
CDL	float satellite_longitude(time,scanline) ; satellite_longitude:units = "degrees_east" ; satellite_longitude:valid_min = -180.f ; satellite_longitude:valid_max = 180.f ;		
Remarks			

Table 71: CDL definition satellite_longitude variable

8.36 Variable: satellite_altitude

	Variable	Storage type	Units
	satellite_altitude	float	m
CDL	float satellite_altitude(time,scanline) ; satellite_altitude:long_name = "satellite altitude" ; satellite_altitude:units = "m" ; satellite_altitude:valid_min = 700000.f ; satellite_altitude:valid_max = 900000.f ;		
Remarks			

Table 72: CDL definition satellite_altitude variable

8.37 Variable: satellite_orbit_phase

The orbit phase is defined as $1/(2\pi)$ times the angle in radians traversed by the spacecraft since spacecraft midnight as seen from the center of the Earth. Spacecraft midnight is the point on the night side of the Earth where the spacecraft crosses the orbital plane of the Earth about the Sun. This makes the orbit phase a quantity that runs from 0 to 1, while the spacecraft moves between each spacecraft midnight.

	Variable	Storage type	Units
	satellite_orbit_phase	float	none
CDL	float satellite_orbit_phase(time,scanline) ; satellite_orbit_phase:long_name = "fractional satellite orbit phase" ; satellite_orbit_phase:units = "1" ; satellite_orbit_phase:valid_min = -0.02f ; satellite_orbit_phase:valid_max = 1.02f ; satellite_orbit_phase:comment = "Relative offset (0.0 ... 1.0) of the measurement in the orbit" ;		
Remarks	CF-Convention: The conforming unit for quantities that represent fractions, or parts of a whole, is "1".		

Table 73: CDL definition satellite_orbit_phase variable

8.38 Variable: earth_sun_distance

	Variable	Storage type	Units
	earth_sun_distance	float	astronomical unit

CDL

```
float earth_sun_distance(time) ;
earth_sun_distance:long_name = "distance between the earth and the sun" ;
earth_sun_distance:units = "astronomical_unit" ;
earth_sun_distance:valid_min = 0.98f ;
earth_sun_distance:valid_max = 1.02f ;
earth_sun_distance:comment = "1 ua equals 149,597,870,700 meters" ;
```

Remarks

Table 74: CDL definition earth_sun_distance variable

8.39 Variable: processing_class

Different operating modes of the system and the derived L01B products are described by three parameters: the Processing Class, the Instrument Configuration ID (IcID) and Instrument Configuration Version (IcVersion). The concept for these three parameters is taken from the OMI mission:

- The Processing Class defines the type of measurement at a very high level. Contrary to the IcIDs, the set of processing classes is (fairly) static. The advantage of this, is that it is possible to create new IcIDs and as long as these can use an existing processing class, it is not required to update the L01b to support that IcID. Examples of processing classes are Earth_radiance, Sun_irradiance, DLED, WLS, Dark, Background, . . . For a complete overview of valid processing classes see Appendix B.
- The Instrument Configuration ID defines the type of measurement and its purposes. The number of Instrument Configuration IDs will increase over the mission as new types of measurements are created / used;
- The Instrument Configuration Version allows to differentiate between multiple versions for a specific IcID.

Each Processing Class and each IcID corresponds to a number. The numbers for Processing Class, IcID and IcVersion are set in the instrument by the instrument operations team for each measurement.

	Variable	Storage type	Units
	processing_class	short	none

CDL

```
short processing_class(time,scanline) ;
processing_class:long_name = "processing class" ;
processing_class:valid_min = 0 ;
processing_class:valid_max = 255 ;
processing_class:comment = "The processing_class defines the type of
measurement at a very high level.  Contrary to Instrument Configuration IDs,
only a limited, fixed set of processing classes is identified.  Examples
of processing classes are Earth_radiance, Sun_irradiance, CLED, WLS, Dark,
Background, ...;" ;
```

Remarks For a complete overview of valid processing classes see Appendix B.

Table 75: CDL definition processing_class variable

8.40 Variable: instrument_configuration

The TROPOMI instrument has many configurable parameters. For example, the exposure time, co-addition period, gains and (for UVN-DEMs) the binning factors can be varied. As a result, the instrument can be operated in many different modes or configurations. Each combination of instrument settings is referred to as

instrument configuration and is identified by an instrument configuration ID, a number in the range [1,65535]. This instrument configuration ID, or IcID, is primarily used by the instrument, where it identifies an entry in the instrument configuration tables. On ground, the IcID is used to determine the intended purpose of a measurement and is used in the L01b data processing to determine the processing path.

For an IcID, it is possible to have multiple versions, identified by the instrument configuration version or IcVersion. The combination of IcID and IcVersion uniquely identifies the set of configuration settings of the instrument. At a given time, only one IcVersion of an IcID can be active within the instrument. The IcVersion allows to have multiple versions of a measurement with the same purpose, but with different settings. As a result of, for example, instrument degradation, it may be required to change the settings for a measurement. In that case, it is not necessary to create a new IcID, instead the same IcID can be using with a new IcVersion.

Variable	Storage type	Units
`instrument_configuration`	n/a	none

CDL

```
types: instrument_configuration_type {
int icid ;
short ic_version ;
} ;
instrument_configuration_type instrument_configuration(time,scanline) ;
instrument_configuration:long_name = "instrument configuration, IcID and
IcVersion" ;
instrument_configuration:comment = "The Instrument Configuration ID
defines the type of measurement and its purposes. The number of
Instrument Configuration IDs will increase over the mission as new types
of measurements are created / used; The Instrument Configuration Version
allows to differentiate between multiple versions for a specific IcID." ;
```

Remarks

Table 76: CDL definition `instrument_configuration` variable

<TBD #12> Exact definition of instrument_configuration (flags?)

8.41 Variable: `instrument_settings`

The `instrument_settings` is defined differently for UVN and SWIR products.
<TBD #13> Description of instrument settings (dimension nsettings or nid, niv?)

8.41.1 UVN product: instrument_settings

Variable	Storage type	Units
instrument_settings	n/a	none

CDL

```
types: instrument_settings_type {
int icid ;
short ic_version ;
short ic_set ;
short ic_index ;
short processing_class ;
float master_cycle_period ;
float coaddtion_period ;
float exposure_time ;
float msmt_mcp_ft_offset ;
float msmt_mcp_msmt_start_offset ;
float msmt_duration ;
float flush_duration ;
short nr_coadds ;
short cds_gain ;
float pga_gain ;
long master_cycle_period_us ;
long coaddition_period_us ;
long exposure_time_us;
long exposure_period_us ;
short small_pixel_column ;
short stop_column_read ;
short start_column_coad ;
short stop_column_coad ;
short pga_gain_code ;
short dac_offset_code ;
short clock_mode ;
}
instrument_settings_type instrument_settings(nsettings) ;
```

Remarks

Table 77: CDL definition instrument_settings variable

8.41.2 SWIR product: instrument_settings

	Variable	Storage type	Units
	instrument_settings	n/a	none

CDL

```
types:  instrument_settings_type {
int icid ;
short ic_version ;
short ic_set ;
short ic_index ;
short processing_class ;
float master_cycle_period ;
float coaddtion_period ;
float exposure_time ;
float msmt_mcp_ft_offset ;
float msmt_mcp_msmt_start_offset ;
float msmt_duration ;
float reset_time ;
short nr_coadds ;
long master_cycle_period_us ;
long coaddition_period_us ;
long exposure_time_us;
long exposure_period_us ;
short small_pixel_column ;
short stop_column_read ;
short start_column_coad ;
short stop_column_coad ;
}
instrument_settings_type instrument_settings(nsettings) ;
```

Remarks

Table 78: CDL definition instrument_settings variable

8.42 Variable: binning_table

	Variable	Storage type	Units
	binning_table	n/a	none

CDL

```
types:  binning_table_type {
short size ;
binning_factor ;
gain ;
detector_start_row ;
detector_stop_row ;
measurement_start_row ;
measurement_stop_row ;
}
binning_table(nsettings,nbinningregions) ;
binning_table:long_name = "binning table settings" ;
```

Remarks

Table 79: CDL definition binning_table variable

<TBD #14> Description of binning table definition??

8.43 Variable: housekeeping_data

Variable	Storage type	Units
housekeeping_data	n/a	none

CDL

```
types:  housekeeping_data_type {
float temp_det1 ;
float temp_det2 ;
float temp_det3 ;
float temp_det4 ;
float data_offset_s ;
float temp_tss_up_neg_x ;
float temp_tss_up_neg_y ;
float temp_tss_up_pos_x ;
float temp_tss_up_pos_y ;
float temp_tss_up_mid ;
float temp_tss_low_mid ;
float temp_tss_low_uvn_obm ;
float temp_tss_up_uvn_obm ;
float temp_obm_swir ;
float temp_tss_solar_baffle_obm ;
float temp_cu_sls_stim ;
float temp_swir_grating ;
float temp_obm_swir_if ;
float temp_pelt_cu_sls1 ;
float temp_pelt_cu_sls2 ;
float temp_pelt_cu_sls3 ;
float temp_pelt_cu_sls4 ;
float temp_pelt_cu_sls5 ;
byte difm_status ;
byte fmm_status ;
byte det1_led_status ;
byte det2_led_status ;
byte det3_led_status ;
byte det4_led_status ;
byte common_led_status ;
byte sls1_led_status ;
byte sls2_led_status ;
byte sls3_led_status ;
byte sls4_led_status ;
byte sls5_led_status ;
byte wls_led_status ;
}
housekeeping_data_type housekeeping_data(time,scanline) ;
```

Remarks

Table 80: CDL definition housekeeping_data variable

<TBD #15> Description of housekeeping data

8.44 Variable: nominal_wavelength

The nominal_wavelength provides for each ground pixel the wavelength measured by a spectral channel and is defined by the design parameters of the instrument. The wavelength values as provided by the nominal_wavelength are based on the Calibration Key Data (CKD) which are input to the L01b processing (section 5). See also the discussion on calibrated_wavelength in section 8.24.

	Variable	Storage type	Units
	nominal_wavelength	float	nm
CDL	float nominal_wavelength(time,ground_pixel,spectral_channel) ; nominal_wavelength:long_name = "spectral channel nominal wavelength" ; nominal_wavelength:standard_name = "radiation_wavelength" ; nominal_wavelength:units = "nm" ; nominal_wavelength:valid_min = 270.f ; nominal_wavelength:valid_max = 300.f ;		
Remarks	The nominal_wavelength provides for each pixel the wavelength measured by a spectral channel and is defined by the design parameters of the instrument. The values mentioned for valid_min and valid_max apply to the Band1 product and serve as an example. The valid values for all products are listed in Table 1 in section 4.2		

Table 81: CDL definition nominal_wavelength variable

8.45 Variable: sample_cycle

The concept of *"sample cycle"* has been introduced to allow for comparison of the different radiance products (i.e. bands). In principle, the eight products all can have different co-addition periods, i.e. the time period in which independent measurements are added in order to reduce the data rate as well as to increase the signal–to-noise ratio. The number of independent measurements is depending on the integration time which differs for each band, but is fixed for a specific instrument configuration.

For all bands measurements start at the same time but because the co-addition time may be different the scanlines may have a different time stamp. However, after a period of length sample_cycle_length the measurement cycle is repeated and again the measurements start at the same time. Thus, within the sample_cycle a fixed number (for a certain instrument configuration) of scanlines is collected, which differ for each radiance product. However, the sample_cycle index is the same for all these products.

	Variable	Storage type	Units
	sample_cycle	int	none
CDL	int sample_cycle(time,scanline) ; sample_cycle:long_name = "sample cycle" ; sample_cycle:units = "1" ; sample_cycle:comment = "sample_cycle provides a sample_cycle index for each scanline; index starts at 0" ;		
Remarks	One unique set of sample_cycle indexes is applicable to all radiance products (i.e. bands) originating from the same orbit.		

Table 82: CDL definition sample_cycle variable

8.46 Variable: sample_cycle_length

	Variable	Storage type	Units
	sample_cycle_length	int	ms
CDL	int sample_cycle_length(time,scanline) ; sample_cycle_length:long_name = "length of sample cycle" ; sample_cycle_length:units = "ms" ;		
Remarks			

Table 83: CDL definition sample_cycle_length variable

Appendix A Estimated product size

Table 84 lists the estimated product sizes for the eight different standard radiance products. This estimation is based on the netCDF product definition as presented in this document, No compression has been applied. The baseline for the granule size of the standard products is one orbit; no sliced products, i.e. products covering a part of the orbit are foreseen.

Near-real time products (NRT) cover approximately one data slice of one total data downlink volume (see chapter 6) rather than one orbit. Because the standard products and NRT products are based on the same netCDF product definition, the product sizes of these slices can be estimated from Table 84 taking into account that the file size is proportional to the number of scanlines.

Detector	**UV**		**UVIS**		**NIR**		**SWIR**	
Band	1	2	3	4	5	6	7	8
`spectral_channel`	385	385	470	470	512	512	500	500
`scanline`	3300	3300	3300	3300	3300	3300	3300	3300
`ground_pixel`	79	316	316	316	316	456	256	256
Product size (GByte)	1.7	4.9	4.9	4.9	4.9	6.5	3.9	3.9

Table 84: Estimated product size of radiance products; these sizes largely depend on the size of the dimensions `spectral_channel`, `scanline` and `ground_pixel`.

Estimated product sizes for the irradiance, calibration and engineering products are presented in the table below (Table 85).

Product	**Product size (GByte)**
Irradiance UVN	0.02
Irradiance SWIR	0.01
Calibration UVN	22.00
Calibration SWIR	5.60
Engineering	0.05

Table 85: Estimated product size irradiance, calibration and engineering products

Appendix B Processing classes

Class	Name	Definition
		Undefined
0	Undefined	Value to indicate that a processing class was explicitly not set
		Nominal modes
1	Earth_radiance	Nominal earth radiance measurement
2	Earth_radiance_special	Earth radiance special mode. Can be used for special radiance measurements that have a special purpose (e.g. specific campaigns, geolocation validation) or require special handling (e.g. zoom modes)
3	Solar_irradiance	Nominal solar irradiance measurement
4	Solar_irradiance_special	Solar Irradiance special mode. Can be used for special irradiance measurements that have a special purpose (e.g. back-up diffuser) or require special handling (e.g. zoom modes)
5-15	-	Reserved for future use
		In-flight calibration modes
16	DLED	Detector LED measurement
17	CLED	Common LED measurement
18	WLS	White Light Source measurement
19	SLS	Spectral Line Source measurement
20	Dark	Dark current measurement
21	Background	Background measurement
22	CTE	UVN CTE measurement (using ClkDrvAb = 1)
23	No_clock	UVN no clocking measurement (using ClkDrvAll = 1)
24	Reverse_clock	UVN reverse clocking measurement (using reverse clocking timing for RiseR* and FallR*)
25	Storage	UVN CCD Storage section characterization measurement
26	Flush	Detector flush mode
27-63	-	Reserved for future use
		Test modes
64	ICU_test	ICU test mode
65	DEM_test	DEM test mode
66	Functional_test	Instrument functional test
67	Processor_test	Data processor software test
68	Auto_optimization	Automated optimization measurement
69-95	-	Reserved for future use
		Modes for specific processing
96	Discard	Discard / ignore data
97	Process_BU	Process data up-to binary units (i.e. no processing)
98	Process_electrons	Process data up-to electrons
99	Process_electron_flux	Process data up-to electrons per second
100	Process_photon_flux	Process data up-to photons per second (similar to Earth radiance)
101-127	-	Reserved for future use

Class	Name	Definition
		On-ground calibration modes
128	OCAL	Generic on-ground calibration processing, nominal mode
129	OCAL_special	Generic on-ground calibration processing, special mode
130-200	-	Reserved for future use
201	OCAL_radiance	Nominal on-ground calibration radiance measurement
202	OCAL_radiance_special	On-ground calibration radiance special mode
203	OCAL_irradiance	Nominal on-ground calibration irradiance measurement
204	OCAL_irradiance_special	On-ground calibration irradiance special mode
205-215	-	Reserved for future use
216	OCAL_DLED	On-ground calibration detector LED measurement
217	OCAL_CLED	On-ground calibration common LED measurement
218	OCAL_WLS	On-ground calibration White Light Source measurement
219	OCAL_SLS	On-ground calibration Spectral Line Source measurement
220	OCAL_Dark	On-ground calibration dark current measurement
221	OCAL_Background	On-ground calibration background measurement
222	OCAL_CTE	On-ground calibration UVN CTE measurement (using ClkDrvAb = 1)
223	OCAL_No_clock	On-ground calibration UVN no clocking measurement (using ClkDrvAll = 1)
224	OCAL_Reverse_clock	On-ground calibration UVN reverse clocking measurement (using reverse clocking timing for RiseR* and FallR*)
225	OCAL_Storage	On-ground calibration UVN CCD Storage section characterization measurement
226	OCAL_Flush	On-ground calibration detector flush mode
227-255	-	Reserved for future use
		Unused
Values 256 through 32767 are not used.		

Table 86: Processing classes

Appendix C Example EO-FFS .HDR file

Listing 3 shows an example of the .HDR file for L1b products as defined in the “Earth Observation Ground Station File Format Standard (EO-FFS)” standard [AD6].

Listing 3: Example .HDR file

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<Earth_Explorer_File xmlns:gco="http://www.isotc211.org/2005/gco"
    xmlns:gmd="http://www.isotc211.org/2005/gmd"
    xmlns:gmi="http://www.isotc211.org/2005/gmi"
    xmlns:gmx="http://www.isotc211.org/2005/gmx" schemaVersion="1.0"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.knmi.nl/s5p/1.0 Sentinel5PSchema.xsd"
    xmlns="http://www.knmi.nl/s5p/1.0">
  <Earth_Explorer_Header>
    <Fixed_Header>
      <File_Name>S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_
          00140_02_010203_20151204T093045</File_Name>
      <File_Description>Sentinel-5p TROPOMI Level 1b radiance
          product</File_Description>
      <Notes/>
      <Mission>Sentinel-5P</Mission>
      <File_Class>OPER</File_Class>
      <File_Type>L1B_RA_BD1</File_Type>
      <Validity_Period>
        <Validity_Start>UTC=2015-11-14T11:45:11</Validity_Start>
        <Validity_Stop>UTC=2015-11-14T12:15:59</Validity_Stop>
      </Validity_Period>
      <File_Version>L1B_RA_BD1</File_Version>
      <Source>
        <System>DLR PDGS</System>
        <Creator>L10b processor</Creator>
        <Creator_Version>1.2.3</Creator_Version>
        <Creation_Date>UTC=2015-12-04T09:30:45</Creation_Date>
      </Source>
    </Fixed_Header>
    <Variable_Header>
      <gmd:LI_Lineage>
        <gmd:statement>
          <gco:CharacterString>L1b radiance dataset produced by the DLR PDGS from the
              S5p TROPOMI L0 product</gco:CharacterString>
        </gmd:statement>
        <gmd:processStep>
          <gmi:LE_ProcessStep>
            <gmd:description>
              <gco:CharacterString>Processing of L0 to L1b data using the KNMI l01b
                  processor</gco:CharacterString>
            </gmd:description>
            <gmd:source>
              <gmi:LE_Source>
                <gmd:description>
                  <gco:CharacterString>TROPOMI L0 product</gco:CharacterString>
                </gmd:description>
                <gmi:processedLevel>
                  <gmd:MD_Identifier>
                    <gmd:code>
                      <gco:CharacterString>L0</gco:CharacterString>
                    </gmd:code>
```

```
            </gmd:MD_Identifier>
          </gmi:processedLevel>
        </gmi:LE_Source>
      </gmd:source>
      <gmi:output>
        <gmi:LE_Source>
          <gmd:description>
            <gco:CharacterString>TROPOMI L1b radiance
                product</gco:CharacterString>
          </gmd:description>
          <gmd:sourceCitation>
            <gmd:CI_Citation>
              <gmd:title>
                <gmx:FileName>S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_
                    00140_02_010203_20151204T093045.nc</gmx:FileName>
              </gmd:title>
              <gmd:date>
                <gmd:CI_Date>
                  <gmd:date>
                    <gco:Date>2015-11-14</gco:Date>
                  </gmd:date>
                  <gmd:dateType>
                    <gmd:CI_DateTypeCode
                        codeList="http://www.isotc211.org/2005/resources/Codelist/
                        gmxCodelists.xml#CI_DateTypeCode"
                        codeListValue="creation">creation</gmd:CI_DateTypeCode>
                  </gmd:dateType>
                </gmd:CI_Date>
              </gmd:date>
              <gmd:identifier>
                <gmd:MD_Identifier>
                  <gmd:code>
                    <gco:CharacterString>L1B_RA_BD1</gco:CharacterString>
                  </gmd:code>
                </gmd:MD_Identifier>
              </gmd:identifier>
            </gmd:CI_Citation>
          </gmd:sourceCitation>
          <gmi:processedLevel>
            <gmd:MD_Identifier>
              <gmd:code>
                <gco:CharacterString>L1b</gco:CharacterString>
              </gmd:code>
            </gmd:MD_Identifier>
          </gmi:processedLevel>
        </gmi:LE_Source>
      </gmi:output>
      <gmi:processingInformation>
        <gmi:LE_Processing>
          <gmi:identifier>
            <gmd:MD_Identifier>
              <gmd:code>
                <gco:CharacterString>KNMI L01b processor</gco:CharacterString>
              </gmd:code>
            </gmd:MD_Identifier>
          </gmi:identifier>
          <gmi:softwareReference>
            <gmd:CI_Citation>
```

```
                <gmd:title>
                  <gco:CharacterString>L01b processor
                      description</gco:CharacterString>
                </gmd:title>
                <gmd:date>
                  <gmd:CI_Date>
                    <gmd:date>
                      <gco:Date>2014-12-31</gco:Date>
                    </gmd:date>
                    <gmd:dateType>
                      <gmd:CI_DateTypeCode
                          codeList="http://www.isotc211.org/2005/resources/Codelist/
                          gmxCodelists.xml#CI_DateTypeCode"
                          codeListValue="creation">creation</gmd:CI_DateTypeCode>
                    </gmd:dateType>
                  </gmd:CI_Date>
                </gmd:date>
              </gmd:CI_Citation>
            </gmi:softwareReference>
            <gmi:documentation>
              <gmd:CI_Citation>
                <gmd:title>
                  <gmx:FileName>S5P-KNMI-L01B-0009-SD-algorithm_theoretical_
                      basis_document-3.0.0-20140707.pdf</gmx:FileName>
                </gmd:title>
                <gmd:date>
                  <gmd:CI_Date>
                    <gmd:date>
                      <gco:Date>2014-07-07</gco:Date>
                    </gmd:date>
                    <gmd:dateType>
                      <gmd:CI_DateTypeCode
                          codeList="http://www.isotc211.org/2005/resources/Codelist/
                          gmxCodelists.xml#CI_DateTypeCode"
                          codeListValue="publication">publication
                          </gmd:CI_DateTypeCode>
                    </gmd:dateType>
                  </gmd:CI_Date>
                </gmd:date>
              </gmd:CI_Citation>
            </gmi:documentation>
            <gmi:documentation>
              <gmd:CI_Citation>
                <gmd:title>
                  <gmx:FileName>S5P-KNMI-L01B-0012-SD-input_output_data_
                      specification-3.0.0-20140707.pdf</gmx:FileName>
                </gmd:title>
                <gmd:date>
                  <gmd:CI_Date>
                    <gmd:date>
                      <gco:Date>2014-07-07</gco:Date>
                    </gmd:date>
                    <gmd:dateType>
                      <gmd:CI_DateTypeCode
                          codeList="http://www.isotc211.org/2005/resources/Codelist/
                          gmxCodelists.xml#CI_DateTypeCode"
                          codeListValue="publication">publication
                          </gmd:CI_DateTypeCode>
```

```
                    </gmd:dateType>
                  </gmd:CI_Date>
                </gmd:date>
              </gmd:CI_Citation>
            </gmi:documentation>
          </gmi:LE_Processing>
        </gmi:processingInformation>
        <gmi:report>
          <gmi:LE_ProcessStepReport>
            <gmi:name>
              <gco:CharacterString>TROPOMI L01b processing
                  report</gco:CharacterString>
            </gmi:name>
            <gmi:description>
              <gco:CharacterString>L0 processed to L1b data using the KNMI l01b
                  processor</gco:CharacterString>
            </gmi:description>
            <gmi:fileType>
              <gco:CharacterString>netCDF</gco:CharacterString>
            </gmi:fileType>
          </gmi:LE_ProcessStepReport>
        </gmi:report>
      </gmi:LE_ProcessStep>
    </gmd:processStep>
  </gmd:LI_Lineage>
 </Variable_Header>
</Earth_Explorer_Header>
</Earth_Explorer_File>
```

Appendix D Example NcML metadata

Listings 4, 5 and 6 show examples of three different metadata groups, ISO_METADATA, EOP_METADATA and ESA_METADATA represented in NcML.

Listing 4: Example ISO metadata represented in NcML

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2">
  <group name="METADATA">
    <group name="ISO_METADATA">
      <attribute name="objectType" value="gmi:MI_Metadata"/>
      <attribute name="gmd:fileIdentifier"
          value="urn:ogc:def:EOP:ESA:SENTINEL.S5P_TROP_L1B_RAD_BD1"/>
      <group name="gmd:language">
        <attribute name="objectType" value="gmd:LanguageCode"/>
        <attribute name="codeList" value="http://www.loc.gov/standards/iso639-2/"/>
        <attribute name="codeListValue" value="eng"/>
      </group>
      <group name="gmd:characterSet">
        <attribute name="objectType" value="gmd:MD_CharacterSetCode"/>
        <attribute name="codeList"
            value="http://www.isotc211.org/2005/resources/Codelist/
            gmxCodelists.xml#MD_CharacterSetCode"/>
        <attribute name="codeListValue" value="utf8"/>
      </group>
      <group name="gmd:hierarchyLevel">
        <attribute name="objectType" value="gmd:MD_ScopeCode"/>
        <attribute name="codeList"
            value="http://www.isotc211.org/2005/resources/Codelist/
            gmxCodelists.xml#MD_ScopeCode"/>
        <attribute name="codeListValue" value="series"/>
      </group>
      <attribute name="gmd:hierarchyLevelName" value="EO Product Collection"/>
      <group name="gmd:contact">
        <attribute name="objectType" value="gmd:CI_ResponsibleParty"/>
        <attribute name="gmd:individualName" value="KNMI Help"/>
        <attribute name="gmd:organisationName" value="KNMI"/>
        <attribute name="gmd:positionName" value="Help Desk"/>
        <group name="gmd:contactInfo">
          <attribute name="objectType" value="gmd:CI_Contact"/>
          <group name="gmd:address">
            <attribute name="objectType" value="gmd:CI_Address"/>
            <attribute name="gmd:electronicMailAddress" value="info@knmi.nl"/>
          </group>
        </group>
        <group name="gmd:role">
          <attribute name="objectType" value="gmd:CI_RoleCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#CI_RoleCode"/>
          <attribute name="codeListValue" value="pointOfContact"/>
        </group>
      </group>
      <attribute name="gmd:dateStamp" value="2014-11-14"/>
      <attribute name="gmd:metadataStandardName" value="ISO 19115-2 Geographic
          Information - Metadata Part 2 Extensions for imagery and gridded data"/>
      <attribute name="gmd:metadataStandardVersion" value="ISO 19115-2:2009(E), S5P
          profile"/>
```

```
    <group name="gmd:identificationInfo">
      <attribute name="objectType" value="gmd:MD_DataIdentification"/>
      <group name="gmd:citation">
        <attribute name="objectType" value="gmd:CI_Citation"/>
        <attribute name="gmd:title" value="S5p TROPOMI Radiance L1b product"/>
        <group name="gmd:date">
          <attribute name="objectType" value="gmd:CI_Date"/>
          <attribute name="gmd:date" value="2014-11-14"/>
          <group name="gmd:dateType">
            <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
            <attribute name="codeList"
                value="http://www.isotc211.org/2005/resources/Codelist/
                gmxCodelists.xml#CI_DateTypeCode"/>
            <attribute name="codeListValue" value="creation"/>
          </group>
        </group>
        <group name="gmd:identifier">
          <attribute name="objectType" value="gmd:MD_Identifier"/>
          <attribute name="gmd:code"
              value="urn:ogc:def:EOP:ESA:SENTINEL.S5P_TROP_L1B_RAD_BD1"/>
        </group>
      </group>
      <attribute name="gmd:abstract" value="S5p TROPOMI instrument measures..."/>
      <attribute name="gmd:credit" value="Financial support by NSO"/>
      <group name="gmd:pointOfContact">
        <attribute name="objectType" value="gmd:CI_ResponsibleParty"/>
        <attribute name="gmd:individualName" value="eoHelp"/>
        <attribute name="gmd:organisationName" value="ESA"/>
        <attribute name="gmd:positionName" value="Order Desk"/>
        <group name="gmd:contactInfo">
          <attribute name="objectType" value="gmd:CI_Contact"/>
          <group name="gmd:address">
            <attribute name="objectType" value="gmd:CI_Address"/>
            <attribute name="gmd:electronicMailAddress" value="eohelp@esa.int"/>
          </group>
        </group>
        <group name="gmd:role">
          <attribute name="objectType" value="gmd:CI_RoleCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#CI_RoleCode"/>
          <attribute name="codeListValue" value="distributor"/>
        </group>
      </group>
      <group name="gmd:descriptiveKeywords">
        <attribute name="objectType" value="gmd:MD_Keywords"/>
        <attribute name="gmd:keyword" value="orthoimagery"/>
        <group name="gmd:type">
          <attribute name="objectType" value="gmd:MD_KeywordTypeCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#MD_KeywordTypeCode"/>
          <attribute name="codeListValue" value="theme"/>
        </group>
        <group name="gmd:thesaurusName">
          <attribute name="objectType" value="gmd:CI_Citation"/>
          <attribute name="gmd:title" value="GEMET - INSPIRE themes, version 1.0"/>
          <group name="gmd:date">
```

```
            <attribute name="objectType" value="gmd:CI_Date"/>
            <attribute name="gmd:date" value="2008-06-01"/>
            <group name="gmd:dateType">
              <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
              <attribute name="codeList"
                  value="http://www.isotc211.org/2005/resources/Codelist/
                  gmxCodelists.xml#CI_DateTypeCode"/>
              <attribute name="codeListValue" value="publication"/>
            </group>
          </group>
        </group>
        <group name="gmd:resourceConstraints">
          <attribute name="objectType" value="gmd:MD_LegalConstraints"/>
          <attribute name="gmd:useLimitation" value="no conditions apply"/>
          <group name="gmd:accessConstraints">
            <attribute name="objectType" value="gmd:MD_RestrictionCode"/>
            <attribute name="codeList"
                value="http://www.isotc211.org/2005/resources/Codelist/
                gmxCodelists.xml#MD_RestrictionCode"/>
            <attribute name="codeListValue" value="copyright"/>
          </group>
        </group>
        <group name="gmd:spatialRepresentationType">
          <attribute name="objectType" value="gmd:MD_SpatialRepresentationTypeCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#MD_SpatialRepresentationTypeCode"/>
          <attribute name="codeListValue" value="grid"/>
        </group>
        <group name="gmd:spatialResolution">
          <attribute name="objectType" value="gmd:MD_Resolution"/>
          <attribute name="gmd:distance" value="7.0"/>
          <attribute name="uom" value="km"/>
        </group>
        <attribute name="gmd:language" value="eng"/>
        <group name="gmd:characterSet">
          <attribute name="objectType" value="gmd:MD_CharacterSetCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#MD_CharacterSetCode"/>
          <attribute name="codeListValue" value="utf8"/>
        </group>
        <attribute name="gmd:topicCategory" value="imageryBaseMapsEarthCover"/>
        <group name="gmd:extent">
          <attribute name="objectType" value="gmd:EX_Extent"/>
          <group name="gmd:geographicElement">
            <attribute name="objectType" value="gmd:EX_GeographicBoundingBox"/>
            <attribute name="gmd:westBoundLongitude" value="-180.0"/>
            <attribute name="gmd:eastBoundLongitude" value="180.0"/>
            <attribute name="gmd:southBoundLatitude" value="-90.0"/>
            <attribute name="gmd:northBoundLatitude" value="90.0"/>
          </group>
          <group name="gmd:temporalElement">
            <attribute name="objectType" value="gmd:EX_TemporalExtent"/>
            <group name="gmd:extent">
              <attribute name="objectType" value="gml:TimePeriod"/>
              <attribute name="gml:beginPosition" value="2014-11-14T19:58:00"/>
```

```
            <attribute name="gml:endPosition" value="2014-11-14T20:08:00"/>
          </group>
        </group>
      </group>
    </group>
    <group name="gmd:dataQualityInfo">
      <attribute name="objectType" value="gmd:DQ_DataQuality"/>
      <group name="gmd:scope">
        <attribute name="objectType" value="gmd:DQ_Scope"/>
        <group name="gmd:level">
          <attribute name="objectType" value="gmd:MD_ScopeCode"/>
          <attribute name="codeList"
              value="http://www.isotc211.org/2005/resources/Codelist/
              gmxCodelists.xml#MD_ScopeCode"/>
          <attribute name="codeListValue" value="dataset"/>
        </group>
      </group>
      <group name="gmd:report">
        <attribute name="objectType" value="gmd:DQ_DomainConsistency"/>
        <group name="gmd:result">
          <attribute name="objectType" value="gmd:DQ_ConformanceResult"/>
          <group name="gmd:specification">
            <attribute name="objectType" value="gmd:CI_Citation"/>
            <attribute name="gmd:title" value="INSPIRE Data Specification on
                Orthoimagery - Guidelines, version 3.0rc3"/>
            <group name="gmd:date">
              <attribute name="objectType" value="gmd:CI_Date"/>
              <attribute name="gmd:date" value="2013-02-04"/>
              <group name="gmd:dateType">
                <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
                <attribute name="codeList"
                    value="http://www.isotc211.org/2005/resources/Codelist/
                    gmxCodelists.xml#CI_DateTypeCode"/>
                <attribute name="codeListValue" value="publication"/>
              </group>
            </group>
          </group>
          <attribute name="gmd:explanation" value="INSPIRE Data specification for
              orthoimagery is not yet officially published so conformity has not yet
              been evaluated."/>
          <attribute name="gmd:pass" value="true"/>
        </group>
      </group>
      <group name="gmd:lineage">
        <attribute name="objectType" value="gmd:LI_Lineage"/>
        <attribute name="gmd:statement" value="L1b radiance dataset produced by the
            DLR PDGS from the S5p TROPOMI L0 product"/>
        <group name="gmd:processStep">
          <attribute name="objectType" value="gmi:LE_ProcessStep"/>
          <attribute name="gmd:description" value="Processing of L0 to L1b data
              using the KNMI l01b processor"/>
          <group name="gmd:source">
            <attribute name="objectType" value="gmi:LE_Source"/>
            <attribute name="gmd:description" value="TROPOMI L0 product"/>
            <group name="gmi:processedLevel">
              <attribute name="objectType" value="gmd:MD_Identifier"/>
              <attribute name="gmd:code" value="L0"/>
            </group>
```

```
        </group>
        <group name="gmi:output">
          <attribute name="objectType" value="gmi:LE_Source"/>
          <attribute name="gmd:description" value="TROPOMI L1b radiance product"/>
          <group name="gmd:sourceCitation">
            <attribute name="objectType" value="gmd:CI_Citation"/>
            <attribute name="gmd:title"
                value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
                _02_010203_20151204T093045.nc"/>
            <group name="gmd:date">
              <attribute name="objectType" value="gmd:CI_Date"/>
              <attribute name="gmd:date" value="2015-11-14"/>
              <group name="gmd:dateType">
                <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
                <attribute name="codeList"
                    value="http://www.isotc211.org/2005/resources/Codelist/
                    gmxCodelists.xml#CI_DateTypeCode"/>
                <attribute name="codeListValue" value="creation"/>
              </group>
            </group>
            <group name="gmd:identifier">
              <attribute name="objectType" value="gmd:MD_Identifier"/>
              <attribute name="gmd:code" value="L1B_RA_BD1"/>
            </group>
          </group>
          <group name="gmi:processedLevel">
            <attribute name="objectType" value="gmd:MD_Identifier"/>
            <attribute name="gmd:code" value="L1b"/>
          </group>
        </group>
        <group name="gmi:processingInformation">
          <attribute name="objectType" value="gmi:LE_Processing"/>
          <group name="gmi:identifier">
            <attribute name="objectType" value="gmd:MD_Identifier"/>
            <attribute name="gmd:code" value="KNMI L01b processor"/>
          </group>
          <group name="gmi:softwareReference">
            <attribute name="objectType" value="gmd:CI_Citation"/>
            <attribute name="gmd:title" value="L01b processor description"/>
            <group name="gmd:date">
              <attribute name="objectType" value="gmd:CI_Date"/>
              <attribute name="gmd:date" value="2014-12-31"/>
              <group name="gmd:dateType">
                <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
                <attribute name="codeList"
                    value="http://www.isotc211.org/2005/resources/Codelist/
                    gmxCodelists.xml#CI_DateTypeCode"/>
                <attribute name="codeListValue" value="creation"/>
              </group>
            </group>
          </group>
          <group name="gmi:documentation_1">
            <attribute name="objectType" value="gmd:CI_Citation"/>
            <attribute name="gmd:title"
                value="S5P-KNMI-L01B-0009-SD-algorithm_theoretical_basis_
                document-3.0.0-20140707.pdf"/>
            <group name="gmd:date">
              <attribute name="objectType" value="gmd:CI_Date"/>
```

```
            <attribute name="gmd:date" value="2014-07-07"/>
            <group name="gmd:dateType">
              <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
              <attribute name="codeList"
                  value="http://www.isotc211.org/2005/resources/Codelist/
                  gmxCodelists.xml#CI_DateTypeCode"/>
              <attribute name="codeListValue" value="publication"/>
            </group>
          </group>
        </group>
        <group name="gmi:documentation_2">
          <attribute name="objectType" value="gmd:CI_Citation"/>
          <attribute name="gmd:title"
              value="S5P-KNMI-L01B-0012-SD-input_output_data_
              specification-3.0.0-20140707.pdf"/>
          <group name="gmd:date">
            <attribute name="objectType" value="gmd:CI_Date"/>
            <attribute name="gmd:date" value="2014-07-07"/>
            <group name="gmd:dateType">
              <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
              <attribute name="codeList"
                  value="http://www.isotc211.org/2005/resources/Codelist/
                  gmxCodelists.xml#CI_DateTypeCode"/>
              <attribute name="codeListValue" value="publication"/>
            </group>
          </group>
        </group>
      </group>
      <group name="gmi:report">
        <attribute name="objectType" value="gmi:LE_ProcessStepReport"/>
        <attribute name="gmi:name" value="TROPOMI L01b processing report"/>
        <attribute name="gmi:description" value="L0 processed to L1b data using
            the KNMI l01b processor"/>
        <attribute name="gmi:fileType" value="netCDF"/>
      </group>
    </group>
  </group>
</group>
<group name="gmi:acquisitionInformation">
  <attribute name="objectType" value="gmi:MI_AcquisitionInformation"/>
  <group name="gmi:platform">
    <attribute name="objectType" value="gmi:MI_Platform"/>
    <group name="gmi:identifier">
      <attribute name="objectType" value="gmd:RS_Identifier"/>
      <attribute name="gmd:code" value="S5p"/>
      <attribute name="gmd:codeSpace" value="http://www.esa.int/"/>
    </group>
    <attribute name="gmi:description" value="Sentinel 5 Precursor"/>
    <group name="gmi:instrument">
      <attribute name="objectType" value="gmi:MI_Instrument"/>
      <group name="gmi:identifier">
        <attribute name="objectType" value="gmd:RS_Identifier"/>
        <attribute name="gmd:code" value="TROPOMI"/>
        <attribute name="gmd:codeSpace" value="http://www.esa.int/"/>
      </group>
      <group name="gmi:type">
        <attribute name="objectType" value="gmi:MI_SensorTypeCode"/>
        <attribute name="codeList" value=""/>
```

```
            <attribute name="codeListValue" value="UV-VIS-NIR-SWIR imaging
                spectrometer"/>
          </group>
        </group>
      </group>
    </group>
    <group name="EOP_METADATA"/>
    <group name="ESA_METADATA"/>
  </group>
</netcdf>
```

Listing 5: Example EOP metadata represented in NcML

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2">
  <group name="METADATA">
    <group name="ISO_METADATA"/>
    <group name="EOP_METADATA">
      <attribute name="objectType" value="atm:EarthObservation"/>
      <attribute name="gml:id"
          value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
          _02_010203_20151204T093045.ID"/>
      <group name="om:phenomenonTime">
        <attribute name="objectType" value="gml:TimePeriod"/>
        <attribute name="gml:beginPosition" value="2015-11-14T11:45:11"/>
        <attribute name="gml:endPosition" value="2015-11-14T12:15:59"/>
      </group>
      <group name="om:resultTime">
        <attribute name="objectType" value="gml:TimeInstant"/>
        <attribute name="gml:timePosition" value="2015-11-16T19:54:00"/>
      </group>
      <group name="om:procedure">
        <attribute name="objectType" value="eop:EarthObservationEquipment"/>
        <attribute name="gml:id"
            value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
            _02_010203_20151204T093045.EOE"/>
        <group name="eop:platform">
          <attribute name="objectType" value="eop:Platform"/>
          <attribute name="eop:shortName" value="Sentinel-5p"/>
        </group>
        <group name="eop:instrument">
          <attribute name="objectType" value="eop:Instrument"/>
          <attribute name="eop:shortName" value="TROPOMI"/>
        </group>
        <group name="eop:sensor">
          <attribute name="objectType" value="eop:Sensor"/>
          <attribute name="eop:sensorType" value="ATMOSPHERIC"/>
        </group>
        <group name="eop:acquisitionParameters">
          <attribute name="objectType" value="eop:Acquisition"/>
          <attribute name="eop:orbitNumber" value="1234"/>
        </group>
        <group name="eop:acquisitionParameters">
          <attribute name="objectType" value="eop:Acquisition"/>
          <attribute name="eop:orbitNumber" value="1234"/>
        </group>
      </group>
```

```
    <group name="om:observedProperty">
      <attribute name="nilReason" value="inapplicable"/>
    </group>
    <group name="om:featureOfInterest">
      <attribute name="objectType" value="eop:FootPrint"/>
      <attribute name="gml:id"
          value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
          _02_010203_20151204T093045.FP"/>
      <group name="eop:multiExtentOf">
        <attribute name="objectType" value="gml:MultiSurface"/>
        <group name="gml:surfaceMembers">
          <attribute name="objectType" value="gml:Polygon"/>
          <group name="gml:exterior">
            <attribute name="objectType" value="gml:LinearRing"/>
            <attribute name="gml:posList" value="40.8344 47.3123 41.0442 48.6136
                49.507 46.1166 51.1057 45.5826 50.8827 44.0264 40.8344 47.3123"/>
          </group>
        </group>
      </group>
    </group>
    <group name="om:result">
      <attribute name="objectType" value="atm:EarthObservationResult"/>
      <attribute name="gml:id"
          value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
          _02_010203_20151204T093045.EOR"/>
      <group name="eop:product">
        <attribute name="objectType" value="eop:ProductInformation"/>
        <group name="eop:fileName">
          <attribute name="objectType" value="ows:ServiceReference"/>
          <attribute name="xlink:href"
              value="http://some.downlink.url/sentinel5_product.nc"/>
          <attribute name="ows:RequestMessage" value=""/>
        </group>
      </group>
    </group>
    <group name="eop:metaDataProperty">
      <attribute name="objectType" value="eop:EarthObservationMetaData"/>
      <attribute name="eop:identifier"
          value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
          _02_010203_20151204T093045"/>
      <attribute name="eop:parentIdentifier"
          value="urn:ogc:def:EOP:ESA:SENTINEL.S5P_TROP_L1B_RAD_BD1"/>
      <attribute name="eop:aquisitionType" value="NOMINAL"/>
      <attribute name="eop:productType" value="S5P_OPER_L1B_RA_BD1"/>
      <attribute name="eop:status" value="ARCHIVED"/>
      <group name="eop:downlinkedTo">
        <attribute name="objectType" value="eop:DownlinkInformation"/>
        <attribute name="eop:acquisitionStation" value="SVG"/>
        <attribute name="eop:acquisitionDate" value="2015-11-14"/>
      </group>
      <group name="eop:archivedIn">
        <attribute name="objectType" value="eop:ArchivingInformation"/>
        <attribute name="eop:archivingCenter" value="DLR-DFD"/>
        <attribute name="eop:archivingDate" value="2015-11-16"/>
      </group>
      <group name="eop:processing">
        <attribute name="objectType" value="eop:ProcessingInformation"/>
        <attribute name="eop:processingCenter" value="DLR-DFD"/>
```

```
        <attribute name="eop:processingDate" value="2015-11-16"/>
        <attribute name="eop:processorName" value="tropl10b"/>
        <attribute name="eop:processorVersion" value="1.1.1"/>
        <attribute name="eop:processingLevel" value="L1b"/>
      </group>
    </group>
  </group>
  <group name="ESA_METADATA"/>
 </group>
</netcdf>
```

Listing 6: Example ESA metadata represented in NcML

```
<?xml version="1.0" encoding="UTF-8" standalone="no"?>
<netcdf xmlns="http://www.unidata.ucar.edu/namespaces/netcdf/ncml-2.2">
 <group name="METADATA">
  <group name="ISO_METADATA"/>
  <group name="EOP_METADATA"/>
  <group name="ESA_METADATA">
   <attribute name="objectType" value="Earth_Explorer_File"/>
   <group name="earth_explorer_header">
    <attribute name="objectType" value="Earth_Explorer_Header"/>
    <group name="fixed_header">
     <attribute name="objectType" value="Fixed_Header"/>
     <attribute name="File_Name"
         value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
         _02_010203_20151204T093045"/>
     <attribute name="File_Description" value="Sentinel-5p TROPOMI Level 1b
         radiance product"/>
     <attribute name="Notes" value=""/>
     <attribute name="Mission" value="Sentinel-5P"/>
     <attribute name="File_Class" value="OPER"/>
     <attribute name="File_Type" value="L1B_RA_BD1"/>
     <group name="validity_period">
      <attribute name="objectType" value="Validity_Period"/>
      <attribute name="Validity_Start" value="UTC=2015-11-14T11:45:11"/>
      <attribute name="Validity_Stop" value="UTC=2015-11-14T12:15:59"/>
     </group>
     <attribute name="File_Version" value="L1B_RA_BD1"/>
     <group name="source">
      <attribute name="objectType" value="Source"/>
      <attribute name="System" value="DLR PDGS"/>
      <attribute name="Creator" value="L10b processor"/>
      <attribute name="Creator_Version" value="1.2.3"/>
      <attribute name="Creation_Date" value="UTC=2015-12-04T09:30:45"/>
     </group>
    </group>
    <group name="variable_header">
     <attribute name="objectType" value="Variable_Header"/>
     <group name="gmd:lineage">
      <attribute name="objectType" value="gmd:LI_Lineage"/>
      <attribute name="gmd:statement" value="L1b radiance dataset produced by
          the DLR PDGS from the S5p TROPOMI L0 product"/>
      <group name="gmd:processStep">
       <attribute name="objectType" value="gmi:LE_ProcessStep"/>
       <attribute name="gmd:description" value="Processing of L0 to L1b data
           using the KNMI l01b processor"/>
       <group name="gmd:source">
```

```
      <attribute name="objectType" value="gmi:LE_Source"/>
      <attribute name="gmd:description" value="TROPOMI L0 product"/>
      <group name="gmi:processedLevel">
        <attribute name="objectType" value="gmd:MD_Identifier"/>
        <attribute name="gmd:code" value="L0"/>
      </group>
    </group>
    <group name="gmi:output">
      <attribute name="objectType" value="gmi:LE_Source"/>
      <attribute name="gmd:description" value="TROPOMI L1b radiance product"/>
      <group name="gmd:sourceCitation">
        <attribute name="objectType" value="gmd:CI_Citation"/>
        <attribute name="gmd:title"
            value="S5P_OPER_L1B_RA_BD1_20151114T114511_20151114T121559_00140
            _02_010203_20151204T093045.nc"/>
        <group name="gmd:date">
          <attribute name="objectType" value="gmd:CI_Date"/>
          <attribute name="gmd:date" value="2015-11-14"/>
          <group name="gmd:dateType">
            <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
            <attribute name="codeList"
                value="http://www.isotc211.org/2005/resources/Codelist/
                gmxCodelists.xml#CI_DateTypeCode"/>
            <attribute name="codeListValue" value="creation"/>
          </group>
        </group>
        <group name="gmd:identifier">
          <attribute name="objectType" value="gmd:MD_Identifier"/>
          <attribute name="gmd:code" value="L1B_RA_BD1"/>
        </group>
      </group>
      <group name="gmi:processedLevel">
        <attribute name="objectType" value="gmd:MD_Identifier"/>
        <attribute name="gmd:code" value="L1b"/>
      </group>
    </group>
    <group name="gmi:processingInformation">
      <attribute name="objectType" value="gmi:LE_Processing"/>
      <group name="gmi:identifier">
        <attribute name="objectType" value="gmd:MD_Identifier"/>
        <attribute name="gmd:code" value="KNMI L01b processor"/>
      </group>
      <group name="gmi:softwareReference">
        <attribute name="objectType" value="gmd:CI_Citation"/>
        <attribute name="gmd:title" value="L01b processor description"/>
        <group name="gmd:date">
          <attribute name="objectType" value="gmd:CI_Date"/>
          <attribute name="gmd:date" value="2014-12-31"/>
          <group name="gmd:dateType">
            <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
            <attribute name="codeList"
                value="http://www.isotc211.org/2005/resources/Codelist/
                gmxCodelists.xml#CI_DateTypeCode"/>
            <attribute name="codeListValue" value="creation"/>
          </group>
        </group>
      </group>
      <group name="gmi:documentation_1">
```

```
                <attribute name="objectType" value="gmd:CI_Citation"/>
                <attribute name="gmd:title"
                    value="S5P-KNMI-L01B-0009-SD-algorithm_theoretical_basis_
                    document-3.0.0-20140707.pdf"/>
                <group name="gmd:date">
                  <attribute name="objectType" value="gmd:CI_Date"/>
                  <attribute name="gmd:date" value="2014-07-07"/>
                  <group name="gmd:dateType">
                    <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
                    <attribute name="codeList"
                        value="http://www.isotc211.org/2005/resources/Codelist/
                        gmxCodelists.xml#CI_DateTypeCode"/>
                    <attribute name="codeListValue" value="publication"/>
                  </group>
                </group>
              </group>
              <group name="gmi:documentation_2">
                <attribute name="objectType" value="gmd:CI_Citation"/>
                <attribute name="gmd:title"
                    value="S5P-KNMI-L01B-0012-SD-input_output_data_
                    specification-3.0.0-20140707.pdf"/>
                <group name="gmd:date">
                  <attribute name="objectType" value="gmd:CI_Date"/>
                  <attribute name="gmd:date" value="2014-07-07"/>
                  <group name="gmd:dateType">
                    <attribute name="objectType" value="gmd:CI_DateTypeCode"/>
                    <attribute name="codeList"
                        value="http://www.isotc211.org/2005/resources/Codelist/
                        gmxCodelists.xml#CI_DateTypeCode"/>
                    <attribute name="codeListValue" value="publication"/>
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                </group>
              </group>
            </group>
            <group name="gmi:report">
              <attribute name="objectType" value="gmi:LE_ProcessStepReport"/>
              <attribute name="gmi:name" value="TROPOMI L01b processing report"/>
              <attribute name="gmi:description" value="L0 processed to L1b data using
                  the KNMI l01b processor"/>
              <attribute name="gmi:fileType" value="netCDF"/>
            </group>
          </group>
        </group>
      </group>
    </group>
  </group>
</netcdf>
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