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OCO (Orbiting Carbon Observatory) Project
OCO-2

OCO-2 Algorithm Specification Document - Level 1B Process

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OCO-2 Algorithm Specification Document – Level 1B Process

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Change Log

Revision	Date	Sections Changed	Author
Initial	06/1/2014	All	Charles Avis
Rev. A	03/15/2015	1.3 (References), 2.4 (Output Products), 4.2 & 4.3 (new sections on despiking and declocking)	Charles Avis

Table of Contents

1. Introduction

The OCO-2 instrument consists of three co-aligned imaging grating spectrometers recording spectra in the near-infrared. The three spectrometers have different characteristics and are calibrated independently. Their raw data numbers (DN) are delivered correlated in time to the Level 1B process as Level 1A products.

1.1 Objective

The purpose of the Algorithm Specification Document (ASD) is to describe, in computer-science terms, the remote sensing algorithms that produce the Orbiting Carbon Observatory 2 (OCO-2) end-user data products (Level 1B and Level 2). The science basis of an algorithm is not covered in an ASD, but is described in a corresponding Algorithm Theoretical Basis Document (ATBD). The ASD provides a software description of that science as implemented in the operational ground system -- the Science Data Operations System (SDOS). The intent of an ASD is to capture the "as-built" operational implementation of the algorithm. An individual ASD describes the process used in the production of a single level of data product.

1.2 Scope

This document describes the Level 1B process used to generate calibrated radiance products from OCO-2 instrument data.

The Level 1B process covered here converts the raw instrument data numbers into calibrated radiances. This conversion is based upon files of instrument characteristics and algorithm parameters that may vary over time. In addition to calibrated radiances, the Level 1B output products have geolocation information recorded for each measurement for use in higher-level processes.

1.3 References

Reference 1: "OCO (Orbiting Carbon Observatory) - 2 Level 1B Algorithm Theoretical Basis, Version 1.2 Rev 1, March 25, 2015

Reference 2: OCO-2 Data Product User's Guide, Operational L1 and L2 Data Versions 6 and 6R, Revision D, March 2015

Reference 3: OCO-2 SDOS Interface Control Document with the OCO-2 Calibration Team, D-62802, Rev. A

Reference 4: OCO-2 Level 1B Software Interface Specification, D-64066, March 2015

Reference 5: OCO-2 Level 1A Software Interface Specification, D-64071, March 2015

2. Algorithm Description & Software Design

2.1 The Level 1B Role in the OCO-2 Data System

The Level 1B process operates upon both science and calibration observations captured in Level 1A data sets. Dark-current correction and radiometric calibration are applied as defined in Reference 1 with the algorithm constants provided in the Ancillary Radiometric Product (ARP).

2.2 Data System Context

The SDOS Processing System consists of a set of Product Generation Executives (PGE's) and the infrastructure that initiates them and routes data between them. Conceptually, the PGE's can be grouped into processing levels.

- Level 0 Processing prepares incoming datasets for higher-level processing
- Level 1 Processing generates engineering data products and calibrated, geolocated science measurements
- Level 2 Processing generates the X_{CO2} science results

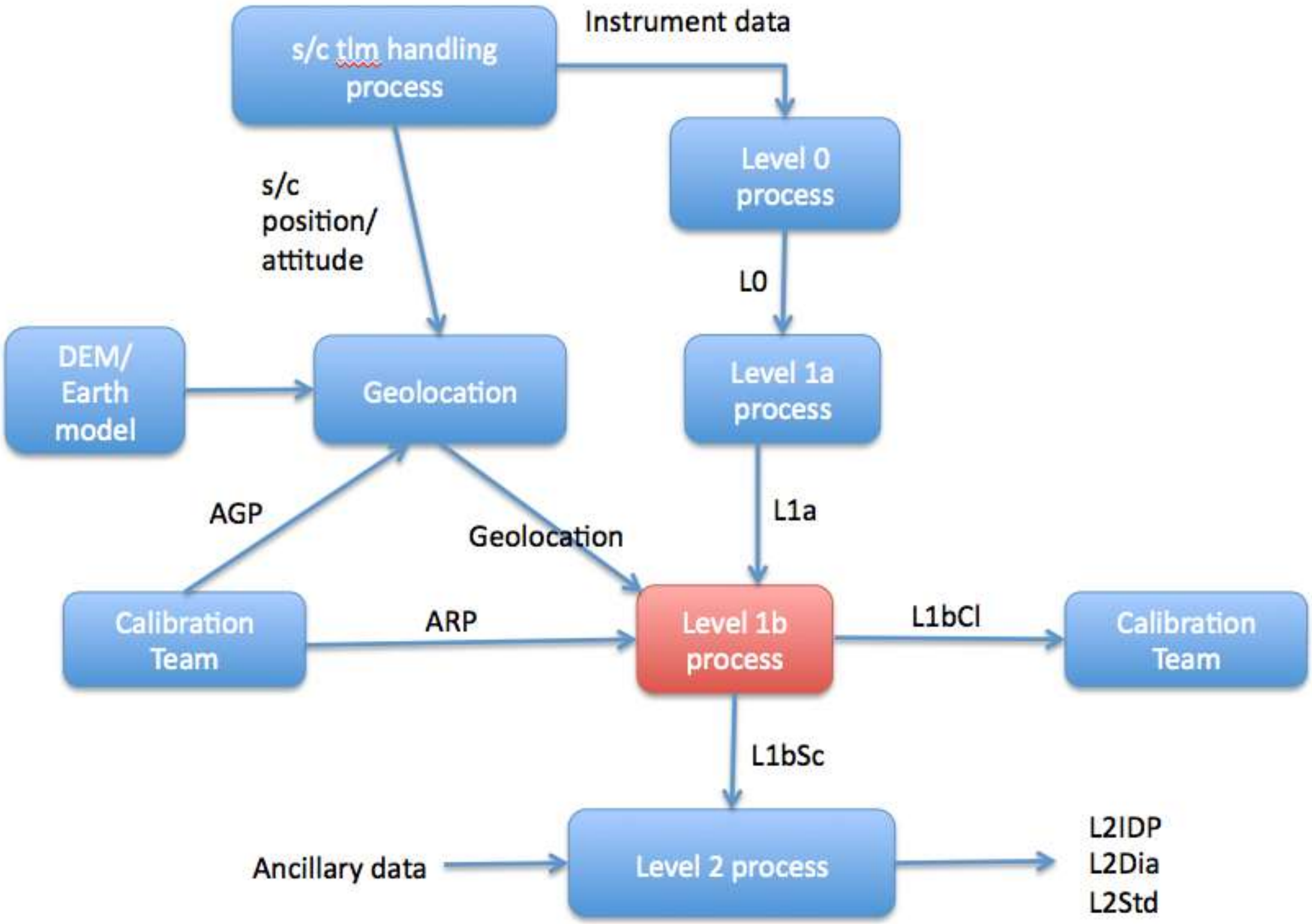
s/c tlm handling process
Instrument data
Level 0 process
s/c position/ attitude
L0
DEM/ Earth model
Geolocation
Level 1a process
AGP
Geolocation
L1a
Calibration Team
ARP
Level 1b process
L1bCl
Calibration Team
L1bSc
Ancillary data
Level 2 process
L2IDP
L2Dia
L2Std

Figure 1

2.3 Input Data Sets

Requirements on Inputs

Level 1a and Geolocation products:

- The data are time-ordered
- The files are in HDF5 format
- Each file contains a single operating mode
- Each file contains a single orbit
- Quality control flags are set

Ancillary Radiometric Product:

- The file covers time range of the Level 1a & Geolocation inputs
- The file is in HDF5 format

Attributes of input products

Level 1A Instrument (L1aIn) - Sample resolution

Description	Collated, parsed, OCO-2 sample resolution science and calibration data for one specific orbit and one specific mode
Coverage	1 per contiguous observation mode in a single orbit (Sample resolution data only)
Format	HDF5

Data groups (described in Reference 5):

Metadata
FrameHeader
EngineeringData
FrameFPATemperatures
SmoothedTemps
FrameConfiguration
CryocoolerData
FrameSampleMeasurements

Geolocation – Science (GeoSc) product

Description	Detailed Earth location of OCO-2 science measurements derived from the spacecraft attitude/position information and a model of the Earth surface
Coverage	1 per contiguous observation mode in a single orbit (Sample resolution science data only)
Format	HDF5

Data groups (copied to the L1bSc product, so described in Reference 4):

Metadata
FrameHeader
FrameGeometry
FootprintGeometry
SoundingGeometry

Geolocation – Calibration (GeoCl) product

Description	Detailed location of OCO-2 calibration measurements
Coverage	1 per contiguous observation mode in a single orbit (Sample resolution calibration data only)
Format	HDF5

Data groups (copied to the L1bCl product, so described in Reference 4):

Metadata
FrameHeader
SpacePointingFrameGeometry

Ancillary Radiometric Product (ARP)

Description	Radiometric and spectral calibration parameters
Format	HDF5

Data groups (described in Reference 3):

Metadata
InstrumentCharacteristics
RadianceConversion
SpectralConversion

2.4 Output Data Sets

Attributes of output products

L1B - Science (L1bSc) product

Description	Spatially ordered, geolocated, calibrated science spectra
Coverage	1 per contiguous observation mode in a single orbit (Sample resolution science data only)
Format	HDF5

Data groups (described in Reference 4):

Metadata
InstrumentHeader
FrameHeader
FrameTemperatures
FrameGeometry
FootprintGeometry
SoundingGeometry
FrameConfiguration
SoundingMeasurements
SliceMeasurements
RadianceClockingCorrection
SpikeEOF

L1B - Calibration (L1bCl) product

Description	Spatially ordered, geolocated, calibrated calibration spectra
Coverage	1 per contiguous observation mode in a single orbit (Sample resolution calibration data only)
Format	HDF5

Data groups (described in Reference 4):

Metadata
InstrumentHeader
FrameHeader
FrameTemperatures
SpacePointingFrameGeometry
FrameConfiguration
SoundingMeasurements
SliceMeasurements
RadianceClockingCorrection
SpikeEOF

3. Overview of Design

The pixel-by-pixel radiometric correction of the measured data numbers is performed by the SDOS component called *CalApp*. Governed by parameter values derived from both ground and flight calibrations, the Level 1B algorithm generates calibrated spectra with associated geolocation parameter values.

Two types of Level 1B products, L1bSc and L1bCl, are generated by *CalApp*. The L1bSc product is generated for all science mode observations (i.e., Earth-pointed). The L1bCl products result from calibration mode measurements (e.g., Lunar, Solar, Dark observations). The differences in the product formats are only in the geolocation information provided. Whereas the L1bSc products report geolocation data for each sounding, calibration products report the direction of the boresight vector.

4. Description of major code sections

CalApp reads the frames of spectrometer data from the L1a product file. Using the instrument time, it extracts the simultaneous engineering data from the same file. Data such as the optics temperature and focal plane temperatures must be associated with the pixel DN measurements.

The radiometric correction of DN measurements to radiance values involves both removal of the appropriate dark-current value and the application of gain coefficients.

4.1 Dark-current

As explained in Reference 1, the dark-current value for a pixel must be estimated from both ground measurements and temperature-based adjustments. *CalApp* reads the ground measurements stored in the ARP and, using the measured temperatures, calculates an appropriate DN adjustment. Applying the equation in Figure 2, the DN value generated by incoming photons is calculated.

4.2 Radiance conversion

For each pixel, *CalApp* reads the radiance conversion gain coefficients from the ARP. Application of the Radiance equation in Figure 2 results in output measurement values store in radiance units (photons/ second/ square-meter/ steradian /micrometer).

No special handling of known bad pixels is performed. These are identified by *snr_coef* values in the ARP but are passed unchanged into the output file. Thus, the downstream processes can skip processing of the bad pixels, if desired.

4.3 Radiance Clocking Correction

After the calculation of radiances, a "clocking "correction is applied to the sample resolution radiance spectra. As noted in the L1B Algorithm Theoretical Basis Document (L1B ATBD; Reference 1), in this instrument design, the spectrometer slits, the grooves on the diffraction gratings, and columns of the Focal Plan Arrays (FPA's) must be well aligned to ensure that a fixed series of rows on the FPA will sample the same spatial footprint throughout the spectral range recorded by each FPA. Perfect alignment of the FPA's was not possible for the OCO-2 instrument. The FPA's are therefore slightly rotated (or "clocked") with respect to the slit and grating. A given geographic position therefore does not map onto a single row of pixels across the entire spectral range sampled by the FPA. Instead, it changes from row to (roughly linearly) with spectral position (i.e., column). This rotation can introduce spectral radiance discontinuities for scenes with substantial variations in illumination across a boundary of two spatial footprints. To mitigate the impact of these discontinuities, a clocking correction algorithm was implemented in the L1B product. This correction is described in the L1B ATBD (Reference 1). The location and size of corrections is stored in the L1B product (see folder RadianceClockingCorrection). The variables in this folder are described in the OCO-2 Data User Guide (Reference 2).

4.4 Spectral Despiking for Cosmic Rays

The radiances are post-processed to detect spurious radiance spikes associated with cosmic rays. Cosmic ray spikes are particularly evident in the vicinity of the South Atlantic Anomaly (see Reference 1). There, the largest spikes are seen in the Oxygen A-band, but they occur in all three spectral channels. An algorithm has been developed to identify and flag the radiance spikes associated with cosmic rays. This algorithm is described in the L1B ATBD (Reference 1). The flags consist of weighted radiance residuals for each spectral sample in each spectrum, which are recorded in the Level 1B product (SpikeEOF/spike_eof_weighted_residual_band, where band=o2, strong_co2, weak_co2). The total number of spectral samples contaminated by cosmic rays in each spectrum is also stored in the L1B file (SpikeEOR/variables spike_eof_bad_colors_band, where band=o2, strong_co2, weak_co2). The OCO-2 Level 2 algorithm uses this information to exclude contaminated spectral samples geographic boundary box around the South Atlantic Anomaly (latitude -50 to 0, longitude -90 to 10 degrees).

4.5 Geolocation

Although *CalApp* does not make use of the geolocation data available in the input data files, it does copy those groups of values into the output product. This data is then associated with the calibrated spectra in a single product for use in downstream applications.

As stated above, the Science observations (which are Earth-looking), get geolocation data referenced to the topographic surface represented by a digital elevation model (DEM). This information thus includes not only locations, but also elevations, slopes, surface type, etc. Calibration observations (not Earth-looking), get Geolocation data about where the boresight was pointed relative to north and zenith.

4.6 Output

CalApp writes the output file in HDF5 format. It maintains the metadata and Geolocation data of the input file, but creates new groups to hold the calibrated radiances (see Section 2.4 above).

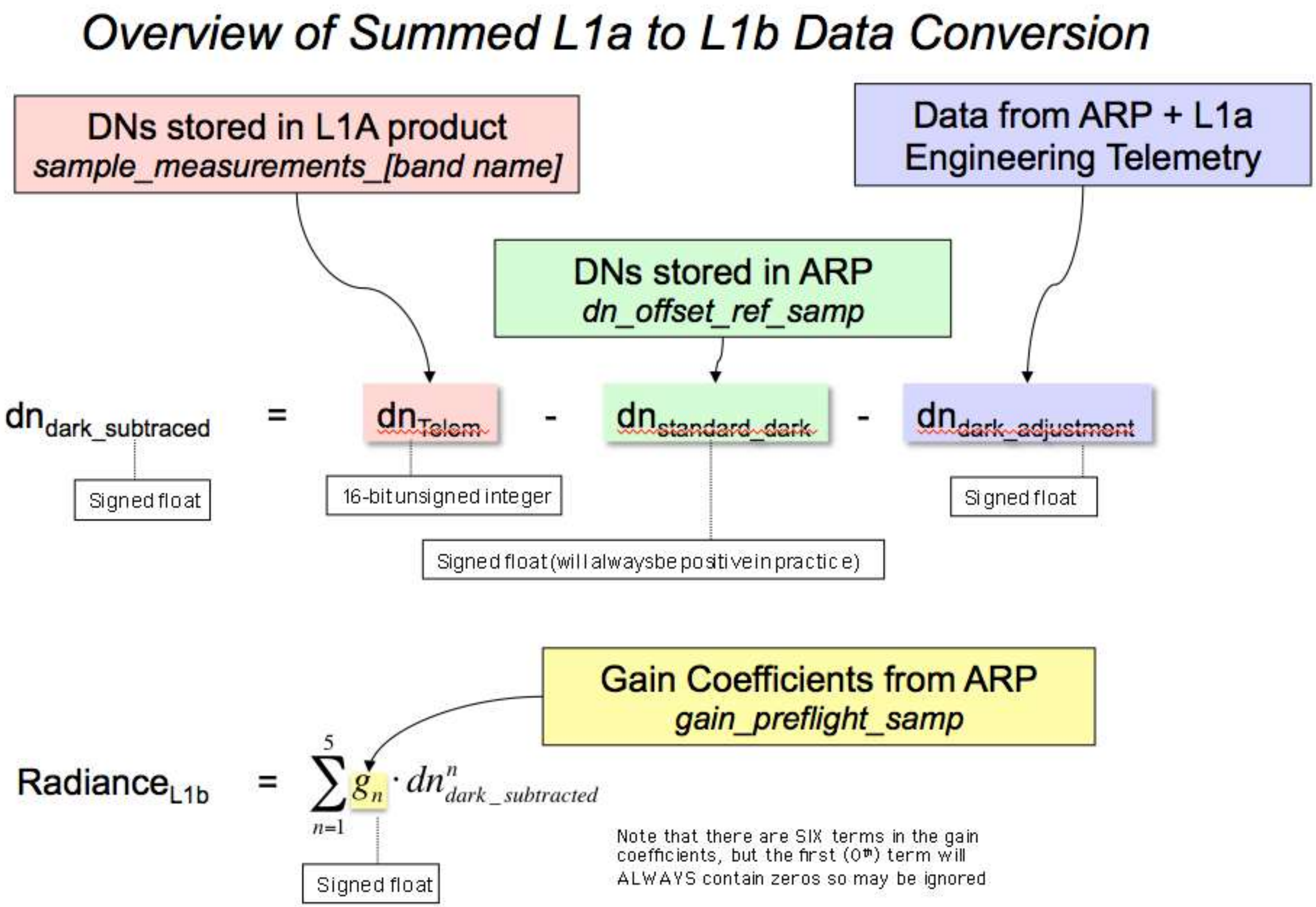
Overview of Summed L1a to L1b Data Conversion
DNs stored in L1A product
sample_measurements_[band name]
Data from ARP + L1a
Engineering Telemetry
DNs stored in ARP
dn_offset_ref_samp
dn_dark_subtraced = dn_Telem - dn_standard_dark - dn_dark_adjustment
Signed float
16-bit unsigned integer
Signed float
Signed float (will always be positive in practice)
Gain Coefficients from ARP
gain_preflight_samp
Radiance_L1b = Σ_{n=1}^{5} g_n · dn^n_dark_subtracted
Signed float
Note that there are SIX terms in the gain
coefficients, but the first (0th) term will
ALWAYS contain zeros so may be ignored

Figure 2

5. Other Considerations

Error handling

Will produce fill data when …

Frames are flagged as bad by Level 1A processing

Geolocation information is not available

Will halt if …

ARP doesn't cover time range

COTS components

HDF libraries

Assumptions and limitations

Operates on sample-resolution data only

Quality assessment and recording

An L1bSc product has three families of quality assessment flags:

- frame_qual_flag
- footprint_bandname_qual_flag
- sounding_qual_flag

In an L1bCl product, only frame_qual_flag and sounding_qual_flag are defined. These flags allow the user filter the data (by frame, footprint or sounding) to avoid various problems discovered by the Level 1B process. For instance, if a frame has incomplete Strong CO_2 band data, bit 4 of the frame_qual_flag is set to 1. In all cases, if a qual flag value is zero, then no issues were noted.

For definitions of these quality flags, see Ref. 4.

Appendix 1 – Acronyms and Glossary

Acronyms

AGP	Ancillary Geometric Product
ARP	Ancillary Radiometric Product
DEM	Digital Elevation Model
DN	Data Number
HDF	Hierarchical Data Format (more information here)
OCO	Orbiting Carbon Observatory
PGE	Product Generation Executable
SDOS	Science Data Operations System

Glossary

Frame	the data structure containing the measurements recorded by one exposure
Footprint	the set of spatial pixels that are summed to make one observation
Sounding	a set of three collocated footprints (one for each spectrometer)
Mode	the instrument configuration set for a particular observation