GOSAT-2/TANSO-CAI-2
Level 1 Data Description Document

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Japan Aerospace Exploration Agency

Contents

1. Introduction 0
1.1. Outline 0
1.2. Baseline Documents 0
2. Overview of products 1
2.1. Definition of processing level 1
2.2. Unit of product 4
2.3. Data contents 5
3. Product format 7
3.1. File name convention 7
3.1.1. File name convention of TANSO-CAI-2 L1A (HDF5 format) 7
3.1.2. Fine name convention of processing result (XML format) 8
3.2. Dataset Structure 9
3.3. Notes for definition of data group 11
3.4. Definition of common file 14
3.4.1. Metadata group 14
3.4.2. SpacecraftTimeError group 14
3.4.3. SiderealTimeInfo group 14
3.4.4. Definition of TransMatrixInfo data group 15
3.4.5. OnboardOrbitData group 15
3.4.6. KinematicOrbitDataPredicted group 15
3.4.7. KinematicOrbitDataDetermined group 15
3.4.8. AttitudeData group 15
3.4.9. SolarEphemeris group 16
3.4.10. LunarEphemeris group 16
3.4.11. TemperatureTelemetry_1sec group 16
3.4.12. TemperatureTelemetry_32sec group 16
3.4.13. HK_Telemetry_1sec group 17
3.5. Definition of Forward/Backward looking band file 18
3.5.1. Metadata group 18
3.5.2. SceneAttribute group 18
3.5.3. LineAttribute_500 group 18
3.5.4. LineAttribute_1km group 18
3.5.5. ImageData group 19
3.5.6. GeometryAttribute group 19
3.5.7. ImageGeometry group 21
3.5.8. SatelliteGeometry group 24
3.5.9. SolarGeometry group 25
3.5.10. LunarGeometry group 25
4. Image Processing 26

4.1. Processing flow 26
4.1.1. Band 2,3,4,7,8 and 9 26
4.1.1. Band 1,6 27
4.1.1. Band 5,10 28
4.2. Radiometric conversion 29
4.3. Band-to-band registration 32
4.4. Saturation correction 33
4.5. Stray light correction for band 1 and 6 35
4.6. Out-of-band stray light correction for band 1 and 6 37
4.7. Band 1 and 6 crosstalk correction 38
4.8. Inter-channel crosstalk correction for band 5 and 10 41
4.9. Stray light correction for band 5 and 10 44
4.10. Filling missing line by interpolation 46
4.11. Image border processing 46
5. Geometric conversion 48
6. Format Details 51

1. Introduction

1.1. Outline

The GOSAT-2 mission is aimed at continuing and advancing GOSAT mission and continuously providing useful information that contributes to environmental decision making for global warming.

GOSAT-2 project is promoted under the cooperation between the Ministry of the Environment (MOE), the Japan Aerospace Exploration Agency (JAXA) and the National Institute for Environmental Studies (NIES).

JAXA implements Level 1 processing of GOSAT-2 data. The Level 1 products based on the observation data of GOSAT-2 is processed by GOSAT-2 Mission Operations System.

This document describes the format of TANSO-CAI-2 Level 1 following products generated by GOSAT-2 Mission Operations System.

- Level 1A product
- Level 1A calibration product

TANSO-CAI-2 Level 1 products are stored in HDF5 (Hierarchical Data Format Version 5). They are produced with HDF5 library.

1.2. Baseline Documents

Following documents give the baseline for the design of products:

(1) HDF5
- HDF5 Reference Manual (Release 1.8.18)
- HDF5 User's Guide(Release 1.8.18)

(2) Engineering Specification Document (ESPC)
- ESPC for global earth observation data processing system (for GOSAT-2), in Japanese
- Definition of GOSAT-2 Level 1 Products, in Japanese

2. Overview of products

2.1. Definition of processing level

Processing of TANSO-CAI-2 level 1 product is defined as follows:

Level 1A processing:

Level 1A products contains uncorrected image data of TANSO-CAI-2, which is stored as digital number together with telemetry of geometric information at observation point, orbit and attitude data, temperature, etc. Uncorrected image data in the product is digital value output from the sensor

Table 2.1-1 shows definitions of TANSO-CAI-2 products.

Table 2.1-2 shows correspondence table of between product and mode and band.

Table 2.1-1 Definition of TANSO-CAI-2 Product

Type	Definition	Operation Mode	Appended information
Level 1A	Level 1A products contain uncorrected image data of TANSO-CAI-2, which is stored as digital number, together with geometric information at observation point and telemetry of temperature, etc. Every scene, the following 4 files are produced. ・ Common file Common information for both Forward looking and Backward looking is stored. ・ Forward looking band file Information for Forward looking is stored (The observation data of band 1-5, etc.). ・ Backward looking band file Information for Backward looking is stored (The observation data of band 6-10, etc.). ・ TANSO-CAI-2 L1 processing result file Quality information, geometric information of representative point and etc. are stored as XML format.	Observation Mode	・ Point number ・ Line exposure time ・ Gain, various sensor temperatures and exposure duration ・ Latitude and longitude at representative point ・ Satellite orbit data at representative point (ECI, ECR) ・ Satellite attitude data at representative point ・ Sensor zenith and azimuth angles at representative point ・ Sun position at representative point (ECI, ECR) ・ Moon position at representative point (ECI, ECR) ・ Quality information
Level 1A Calibration	Same as Level 1A.	Electrical Calibration Dark Calibration Lunar Calibration	Same as Level 1A. In this mode, sensor doesn't observe on the earth surface, therefore information of geolocation, etc. at representative point is not calculated.

Table 2.1-2 Correspondence table of product and mode/band

		TANSO-CAI-2 Observation or Calibration mode	Stored Band
TANSO-CAI-2 L1A Product	Observation (day)	Observation Mode	Forward looking (Band1-5)
			Backward looking (Band6-10)
TANSO-CAI-2 L1A Calibration Product	Dark Calibration	Dark Calibration mode	Forward looking (Band1-5)
			Backward looking (Band6-10)
	Electrical Calibration	Electrical Calibration mode	Forward looking (Band1-5)
			Backward looking (Band6-10)
	Lunar Calibration	Observation Mode (Lunar Calibration)	Forward looking (Band1-5)
			Backward looking (Band6-10)

2.2. Unit of product

Unit of TANSO-CAI-2 level 1 product is described as follows:

(1) One scene product is defined as 1 satellite revolution data starting from ascending node to the next ascending node. If the observation points (satellite position) cross ascending node, the product should be divided into separate products.

(2) Common file, Forward looking band file (for band 1-5) and Backward looking band file (for band 6-10) are produced for both of Observation mode and Calibration mode. Calibration product has plural calibration mode in a product (Night, Electrical, Lunar calibration mode). These calibration data are united together for every calibration mode and stored.

2.3. Data contents

Basic observation modes of TANSO-CAI-2 are shown in Table 2.3-1.

In nominal operation phase, TANSO-CAI-2 sensor of Forward looking observes with band 1-5 and Backward looking observes with band 6-10 during the daytime on earth surface.

Lunar calibration uses the reflected solar irradiance from moon. In this calibration, TANSO-CAI-2 is oriented the moon during night and CAI-2's FOV catches the reflected solar irradiance after attitude maneuver.

Table 2.3-1 Basic observation modes of TANSO-CAI-2

<table>
<tr><th colspan="2">Observation Mode</th><th>Description</th></tr>
<tr><td colspan="2">Observation Mode 1</td><td>Nominal Observation</td></tr>
<tr><td colspan="2">Observation Mode 2</td><td>In the situation that the power supply level of the satellite becomes lower and the satellite cannot keep observation mode1, the observation continues under the condition that a part of function of TANSO-CAI-2 is suspended depending on the power level.</td></tr>
<tr><td rowspan="3">Calibration Mode</td><td>Lunar Calibration</td><td>Once a month
Same as Observation Mode 1 and 2.</td></tr>
<tr><td>Electric Calibration</td><td>Every path
Performs calibration of signal processing after the analogue-signal processing system, by inputting a reference voltage signal.</td></tr>
<tr><td>Dark Calibration</td><td>Once a month as needed.
Same as Observation Mode 1 and 2.
Calibrates the offset level during nighttime.</td></tr>
</table>

Data contents for each processing level and mode are shown in Table 2.3-2.

Table2.3-2 Contents of TANSO-CAI-2 L1 Products

Processing Level	Observation Mode	Used Band	Data Contents (for one observation point)	Data size	Note
1A	Observation Mode	Forward looking band(Band 1-5) Backward looking band (Band 6-10)	Band 1-4, Band 6-9: 2056 pixels. 1^{st}-8^{th} pixel : dark Band 5, Band 10: 1024 pixels 1^{st}-6^{th} pixel: dark 7-66^{th} pixel: invalid	The nominal data size of daytime satellite in a revolution is about 40,000 lines (In case of Band 5,10 are about a half of above, 20,000 lines)	-
1A Calibration	Calibration Mode (Electric Calibration)	ibid	ibid	A series of Electric and Dark calibration data	Input reference voltage signal
	Calibration Mode (Dark Calibration)				Observe earth in night time for acquiring the dark offset level. Acquire the offset level by observing during night time.
	Calibration Mode (Lunar Calibration)	ibid	ibid	A series of Lunar calibration data	Observe Lunar

3. Product format

3.1. File name convention

3.1.1. File name convention of TANSO-CAI-2 L1A (HDF5 format)

Table 3.1-1 shows the file name convention of TANSO-CAI-2 L1A products.

Table3.1-1 File name convention of TANSO-CAI-2 L1A products

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
G	O	S	A	T	2	T	C	A	I	2	Y	Y	Y	Y	M	M	D	D	H	H	m	m	P	P	P	S	S	_	L	L	B	R	C	0	0	O	O	O	O	A	A	A	B	B	B	.	h	5

Convention for each item is shown below

- Satellite Name : GOSAT2 (Fixed)
- Sensor Name : TANSO-CAI-2: TCAI2 (Fixed)
- Observation time at the first line of scene (year・month・day・hour・minute) : YYYYMMDDHHmm (UT)
  Compared with the first line of time of Forward and Backward band, the former line time is nominally stored. Because in nominal case, the start of Forward looking is ahead of that of Backward looking.
- Path No. : PPP(001-089)
- Scene No. : 00(Fixed)
- Processing Level : 1A(Fixed)
- Band : B
  Common file : C
  Forward looking band (Band1-5) : F
  Backward looking band (Band6-10) : B
- Orbit data used for processing : R
  Using predicted orbit data : P
  Using GPS or determined orbit data : D
- Correction coefficients used for processing : C
  Using nominal coefficients : N
  Using updated coefficients : U
- Reserved : 00
- Operation Mode : OOOO
  Observation Mode (day) : OBSM
  Dark calibration mode : NCAL
  Electric calibration mode : ECAL
  Lunar calibration mode : LCAL
- Algorithm Version : AAA (000-999)
- Parameter Version : BBB (000-999)
- Extension : h5 (Fixed)

3.1.2. File name convention of processing result (XML format)

Table 3.1-2 shows File name convention of TANSO-CAI-2 L1 processing result file.

Table3.1-2 File name convention of TANSO-CAI-2 L1 processing result file

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
G	O	S	A	T	2	T	C	A	I	2	Y	Y	Y	Y	M	M	D	D	H	H	m	m	P	P

26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
P	S	S	_	L	L	B	R	C	0	0	O	O	O	O	A	A	A	B	B	B	.	x	m	l

The convention for each item is shown below.

- Satellite Name : GOSAT2 (Fixed)
- Sensor Name : TANSO-CAI-2: TCAI2 (Fixed)
- Start Time of Observation (year・month・day・hour・minute) : YYYYMMDDHHmm (UT)
- Path No. : PPP (001-089)
- Scene No. : 00 (Fixed)
- Processing Level : 1A (Fixed)
- Band : B
  - Common file : C
  - Forward looking band (Band1-5) : F
  - Backward looking band (Band6-10) : B
- Orbit data used for processing : R
  - Using predicted orbit data : P
  - Using GPS or determined orbit data : D
- Correction coefficients used for processing : C
  - Using nominal coefficients : N
  - Using updated coefficients : U
- Reserved : 00
- Operation Mode : OOOO
  - Observation Mode (day) : 0BSM
  - Dark calibration mode : NCAL
  - Electric calibration mode : ECAL
  - Lunar calibration mode : LCAL
- Algorithm Version : AAA (000-999)
- Parameter Version : BBB (000-999)
- Extension : XML (Fixed)

3.2. Dataset Structure

TANSO-CAI-2 L1 product consists of Common file (consists of common information to Forward looking and Backward looking), Forward looking band file (for band 1-5) and Backward looking band file (for band 6-10).

Common file contains metadata, orbit and attitude data, ephemeris data (sun and moon), housekeeping telemetry data such as temperature, status of instruments.

Forward/Backward looking band file contain metadata, Scene Attribute (information of number of pixels, etc.), Line Attribute (line observation time, etc.), Geometric information, Image (digital number for each band), these are Forward/Backward specific information.

Dataset structure of TANSO-CAI-2 L1 product is shown in Table 3.2-1.

Table 3.2-1 Dataset Structure of TANSO-CAI-2 Level 1 Product (1/2)

File	Group	Outline
Common file	Metadata	Items below are stored as explanation of product type, contents, etc. ・Granule ID ・Operation Mode ・Date of product creation ・Processing Level ・Processing Algorithm/Parameter version ・Start and end time of observation ・Quality information
	SpacecraftTimeError	Parameter for correcting spacecraft time error is stored.
	SiderealTimeInfo	Parameter for calculating Greenwich sidereal time is stored.
	TransMatrixInfo	Transform matrix which convert from J2000.0 to TOD and true ECR corresponding polar motion is stored.
	OnboardOrbitData	Onboard orbit data is stored.
	KinematicOrbitDataPredicted	Predicted kinematic orbit data is stored.
	KinematicOrbitDataDetermined	Determined kinematic orbit data is stored.
	AttitudeData	Onboard attitude data is stored.
	SolarEphemeris	Solar position and velocity data is stored.
	LunarEphemeris	Lunar position and velocity data is stored.
	TemperatureTelemetry_1sec	Temperature telemetry of 1 sec period is stored.
	TemperatureTelemetry_32sec	Temperature telemetry of 32 sec period is stored.
	HK_Telemetry_1sec	Housekeeping telemetry of 1sec period is stored.
Forward / Backward looking band file	Metadata	Items below are stored as explanation of product type, contents, etc. ・ Granule ID ・ Operation Mode ・ Date of product creation ・ Processing Level ・ Processing Algorithm Name and its version ・ Start and end time of observation ・
	SceneAttribute	Number of bands, pixels and lines are stored as information about observation point data.

Table 3.2-1 Dataset Structure of TANSO-CAI-2 Level 1 Product (2/2)

File	Group	Outline
	LineAttribute_500	Observed time, missing flag, etc. for each line are stored as information of band 1-4(for Forward looking band file) or 6-9(for Backward looking band file).
	LineAttribute_1km	Observed time, missing flag, etc. for each line are stored as information of band 5(for Forward looking band file) or 10(for Backward looking band file).
	ImageData	Image data is stored.
	GeometryAttribute	Standard band No, sampling interval of both pixel and line direction , number of the sample of both pixel and line direction , etc. are stored as geometric information for reference band
	ImageGeometry	Latitude, longitude, sensor zenith and azimuth angle, solar zenith and azimuth angle, etc. for each sample are stored as geometric information for reference band.
	SatelliteGeometry	Satellite position, velocity and attitude for each line are stored as geometric information for reference band.
	SolarGeometry	Solar position and velocity for each line are stored as geometric information for reference band.
	LunarGeometry	Lunar position and velocity for each line are stored as geometric information for reference band.

3.3. Notes for definition of data group

(1) Definition of data type

Table 3.3-1 describes definition of data type stored in TANSO-CAI-2 L1A products.

Table 3.3-1 Definition of data type

HDF5 type	Data type
H5T_STRING	more than 1 byte string
H5T_STD_I8LE	signed 1byte integer
H5T_STD_U8LE	unsigned 1byte integer
H5T_STD_I16LE	signed 2byte integer
H5T_STD_U16LE	unsigned 2byte integer
H5T_STD_I32LE	signed 4byte integer
H5T_STD_U32LE	unsigned 4byte integer
H5T_IEEE_F32LE	signed 4byte float
H5T_IEEE_F64LE	signed 8byte double

(2) Expression of time

UTC date is expressed as "YYYY-MM-DDThh:mm:ss.ffffffZ" with string data. "YYYY-MM-DD" means year, month and day. "hh:mm" means hour and minute. "ss.ffffffZ" means second with microsecond accuracy.

Spacecraft time is defined as follows:

$$\text{Spacecraft Time (s)} = \text{GPS Time (s)} - 1{,}041{,}033{,}615\text{(s)},$$

where GPS Time (s) is total seconds since 00:00:00 UTC, Jan 6, 1980.

(3) Definition of coordinates

Table 3.3-2 describes definition of coordinates used for dataset.

Table 3.3-2 Definition of coordinates

Name	Abbreviated name	The origin/Axis	Definition	
Inertial coordinate system (J2000.0 coordinate)	Φ_I	The origin:O_I	Earth centered	EPOCH 2000/01/01 12:00:00 TT(Earth time)
		X_I	Direction of mean vernal equinox of EPOCH	
		Y_I	$Z_I \times X_I$	
		Z_I	Vertical direction of mean equatorial plain of EPOCH (Direction of the north pole is +)	
Coordinate Reference Systems in Orbit	Φ_R	The origin:O_R	Ascending node	
		X_R	Coincide with ascending node of orbit coordinate	
		Y_R		
		Z_R		
Orbit coordinate	Φ_O	The origin:Oo	Center of the mass of satellite	Defined by orbit model of AOCE inInertial coordinate system.
		X_O	$Y_O \times Z_O$	
		Y_O	Opposite direction of vector of orbit plane	
		Z_O	Direction of center of the earth	
Coordinate Reference Systems in STT (Reference point for determination of satellite attitude)	Φ_{STT1}	The origin:O_{STT1}	Reference mirror in STT	Defined after early operations phase on orbit
		X_{STT1}	Roll axis in orbit	
		Y_{STT1}	Pitch axis in orbit	
		Z_{STT1}	Yaw axis in orbit	
Satellite coordinate	Φ_B	The origin:O_B	Center of the mass of satellite	Coincide with the orbit coordinate except for attitude error
		X_B	Parallel to each axis of coordinate reference systems in STT	
		Y_B		
		Z_B		
Coordinate Reference Systems in TANSO-CAI-2	Φ_{CAI-2}	The origin:O_{CAI-2}	Transform matrix to convert Satellite coordinate Φ_B from Coordinate Reference Systems in TANSO-CAI-2 is provided as separate file. Ideally, this is stored in unit matrix. The origin is same as satellite coordinate.	
		X_{CAI-2}		
		Y_{CAI-2}		
		Z_{CAI-2}		
Satellite-fixed coordinate	Φ_S	The origin:O_S	Intersection point of center line of and satellite separation plain	
		X_S	Roll axis in machine	
		Y_S	Pitch axis in machine	
		Z_S	Yaw axis in machine	
Earth-fixed coordinate	Φ_{WGS84}	The origin:O_{WGS84}	the gravity center of the earth	GPSR gives absolute position and absolute velocity on this corrdinate
		X_{WGS84}	Coincide with X axis which is defined byBIH for calculation of earth rotation paramerter	
		Y_{WGS84}	$Z_{WGS84} \times X_{WGS84}$	
		Z_{WGS84}	Parallel to Z axis which is defined byBIH for calculation of earth rotation paramerter. Z axis is the direction of CTP.	
TOD coordinate	Φ_{TOD}	The origin:O_{TOD}	Earth centered	
		X_{TOD}	Direction of vernal equinox at the present time	Inertial coordinate system (J2000.0 coordinate)ΦI with taking into precession and nutation.
		Y_{TOD}	$Z_{TOD} \times X_{TOD}$	
		Z_{TOD}	Vertical direction of equatorial plain at the present time (Direction of the north pole is +)	

(4) Definition of latitude/longitude

Unless otherwise specifically noted, latitude and longitude in this document means geographic latitude and longitude.

3.4. Definition of common file

3.4.1. Metadata group

Each dataset in Metadata describes product type, contents, etc which are related to this product file.

Metadata group in common file contains productQualityFlag. productQualityFlag refers to number of missing lines and evaluates quality of product in four levels (Good, Fair, Poor, NG). The criteria are shown below.

When productQualityFlag is Good, there is no missing lines.

Fair/Poor/NG is determined by the threshold value defined in this system. When productQualityFlag is evaluated "NG", product isn't provided to users.

3.4.2. SpacecraftTimeError group

SpacecraftTimeError group contains the information to correct the gap between satellite and the ground station time. If the status of time system is normal, this correction is not required to use.

Formula to correct the time gap is as follows:

Spacecraft time (after correction)
＝periodCount * {spacecraft time(before correction) – refCount} + groundTime

3.4.3. SiderealTimeInfo group

SiderealTimeInfo group contains information of Greenwich sidereal time. Using this information, TOD can be converted to pseudo earth-fixed coordinates (Polar motion is not considered.).

Using Greenwich sidereal time θ_{g0} at the baseline time t_0 and Deviation of Greenwich sidereal time $d\theta_g/dt$ Greenwich sidereal time θ_g at the arbitrary time t is expressed as follows:

$$\theta_g = \theta_{g0} + d\theta_g/dt \times (t - t_0) \qquad \text{Eq. 3.4.3-1}$$

Transform matrix conversion from TOD to pseudo earth-fixed coordinate $\mathbf{M}_{\mathbf{TOD-PECR}}$ is as follows:

$$\mathbf{M}_{\mathbf{TOD-PECR}} = \begin{pmatrix} \cos\theta_g & \sin\theta_g & 0 \\ -\sin\theta_g & \cos\theta_g & 0 \\ 0 & 0 & 1 \end{pmatrix} \qquad \text{Eq. 3.4.3-2}$$

3.4.4. Definition of TransMatrixInfo data group

TransMatrixInfo data group contains PN matrix which can convert from J2000.0 coordinates to TOD coordinates and XY matrix which can convert from pseudo earth-fixed coordinates to ECR coordinates.

Data interval is 60 sec. But in case of the leap second, data interval is 61 sec.

3.4.5. OnboardOrbitData group

OnboardOrbitData group contains onboard orbit data (expressed in ECR coordinates) and orbit data converted to TOD coordinates from onboard orbit data.

Data interval is 1 sec. But in case of data missing, there can be some gap in data interval.

The Conversion method from position vector $\mathbf{P_{ECR}}$ and velocity vector $\mathbf{V_{ECR}}$ of onboard in ECR to position vector $\mathbf{P_{TOD}}$ and velocity vector $\mathbf{V_{TOD}}$ in TOD is described below.

First, $\mathbf{P_{ECR}}$ and $\mathbf{V_{ECR}}$ convert to position vector and velocity vector in pseudo earth-fixed coordinates (This coordinate doesn't consider polar motion) using XY matrix:

$$\mathbf{P_{PECR}} = \mathbf{XY}^t \times \mathbf{P_{ECR}} \qquad \text{Eq. 3.4.5-1}$$

$$\mathbf{V_{PECR}} = \mathbf{XY}^t \times \mathbf{V_{ECR}} \qquad \text{Eq. 3.4.5-2}$$

(The superscript t denotes transpose. Since XY matrix is unitary, transpose of it is the same as its inverse matrix.)

Next, $\mathbf{P_{PECR}}$ and $\mathbf{V_{PECR}}$ convert to $\mathbf{P_{TOD}}$ and $\mathbf{V_{TOD}}$ using Greenwich sidereal time θ_g and Deviation of Greenwich sidereal time $d\theta_g/dt$

$$\mathbf{P_{TOD}} = \begin{pmatrix} \cos(-\theta_g) & \sin(-\theta_g) & 0 \\ -\sin(-\theta_g) & \cos(-\theta_g) & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \mathbf{P_{PECR}} \qquad \text{Eq. 3.4.5-3}$$

$$\mathbf{V_{TOD}} = \begin{pmatrix} \cos(-\theta_g) & \sin(-\theta_g) & 0 \\ -\sin(-\theta_g) & \cos(-\theta_g) & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \left[\mathbf{V_{PECR}} + \begin{pmatrix} 0 \\ 0 \\ \dot{\theta}_g \end{pmatrix} \otimes \mathbf{P_{PECR}} \right]$$

Eq. 3.4.5-4

where $\otimes$ denotes outer product.

3.4.6. KinematicOrbitDataPredicted group

KinematicOrbitDataPredicted group contains predicted kinematic orbit data in ECR and TOD coordinates, this data is distributed from the kinematic orbit system.

In all cases (includes the leap second is inserted), data interval is 60 sec.

3.4.7. KinematicOrbitDataDetermined group

KinematicOrbitDataDetermined group contains determined kinematic orbit data in ECR and TOD coordinates, this data is distributed from the kinematic orbit system.

In all cases (includes the leap second is inserted), data interval is 60 sec.

3.4.8. AttitudeData group

AttitudeData group contains onboard attitude data and yaw steering flag which shows yaw steering operation status.

The data interval is not constant. But, in case of data missing, there can be some gap in data interval.

Attitude data is given in quaternion $Q=(q_0,q_1,q_2,q_3)$ in J2000.0. q_0 is scalar component and (q_1,q_2,q_3) are vector components.

Interpolation is needed to determine attitude data at the given time.

Transform matrix $\mathbf{M}_{\mathbf{J2000\text{-}body}}$ which convert satellite coordinates from J2000.0 coordinates is expressed as follows:

$$\mathbf{M}_{\mathbf{J2000-body}} = \begin{pmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 + q_0q_3) & 2(q_1q_3 - q_0q_2) \\ 2(q_1q_2 - q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 + q_0q_1) \\ 2(q_1q_3 + q_0q_2) & 2(q_2q_3 - q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{pmatrix} \quad \text{Eq. 3.4.8-1}$$

Transform matrix $\mathbf{M}_{\mathbf{body\text{-}J2000}}$ which converts J2000.0 coordinates from satellite coordinates is transpose matrix of $\mathbf{M}_{\mathbf{J2000\text{-}body}}$. $\mathbf{M}_{\mathbf{body\text{-}J2000}}$ is expressed as follows (The superscript t denotes transpose):

$$\mathbf{M}_{\mathbf{body-J2000}} = \left(\mathbf{M}_{\mathbf{J2000-body}}\right)^t = \begin{pmatrix} q_0^2 + q_1^2 - q_2^2 - q_3^2 & 2(q_1q_2 - q_0q_3) & 2(q_1q_3 + q_0q_2) \\ 2(q_1q_2 + q_0q_3) & q_0^2 - q_1^2 + q_2^2 - q_3^2 & 2(q_2q_3 - q_0q_1) \\ 2(q_1q_3 - q_0q_2) & 2(q_2q_3 + q_0q_1) & q_0^2 - q_1^2 - q_2^2 + q_3^2 \end{pmatrix}$$

Eq. 3.4.8-2

3.4.9. SolarEphemeris group

SolarEphemeris group contains the kinematic solar position and velocity data in ECR and TOD coordinates distributed from kinematic orbit system. In all cases (includes the leap second is inserted), data interval is always 60 sec.

Solar position and velocity data are true position and velocity at the time. The light propagation time from sun to earth is not taken in account. However, time data has been recorded since about 10 minutes before start of observation. Thus, solar position and velocity data with taking account of light propagation time can be calculated.

3.4.10. LunarEphemeris group

LunarEphemeris group contains kinematic lunar position and velocity data in ECR and TOD coordinates distributed from kinematic orbit system. In all cases (includes the leap second is inserted), data interval is always 60 sec.

3.4.11. TemperatureTelemetry_1sec group

TemperatureTelemetry_1sec group contains temperature telemetry.

Data interval is 1 sec but there can be some gap in data interval in case of data missing.

The evaluation result about the range of temperature is stored for each data.

Data of sensorTemp, preAmpTemp and ampTemp in this group are used for radiometric conversion. (For the radiometric conversion, see Chapter 4.2)

Temperature data except the above are used for checking sensor condition.

3.4.12. TemperatureTelemetry_32sec group

TemperatureTelemetry_32sec group contains temperature telemetry.

Data interval is 32 sec but there can be some gap in data interval in case of data missing.
The evaluation result about the range of temperature is stored for each data.
The temperature data are used for checking sensor condition.

3.4.13. HK_Telemetry_1sec group

HK_Telemetry_1sec group contains housekeeping telemetry.
Data interval is 1 sec but there can be some gap in data interval in case of data missing.
The telemetry data are used for checking sensor condition.

3.5. Definition of Forward/Backward looking band file

3.5.1. Metadata group

Each dataset in Metadata describes product type, contents, etc are related to this product file.

3.5.2. SceneAttribute group

SceneAttribute group contains number of bands, pixels and lines for each resolution in this product are stored, which are related to this product file.

CAI-2 has 2 resolutions, one is 500 m and 1000 m is the other.

In Forward looking band file, 500 m spatial resolution bands are Band 1-4, total 4 bands and 1 km spatial resolution band is only Band 5.

In Backward looking band file, 500 m spatial resolution bands are Band 6-9,total 4 bands, and 1 km spatial resolution band is only Band 10.

3.5.3. LineAttribute_500 group

LineAttribute_500 group contains the following information for 500 m spatial resolution bands.

- missingFlag
- observationTime
- satTime
- satTimeStatusFlag
- fineobservationCounter
- integrationNum
- exposureTime

observationTime is the center of exposureTime considering the duration of exposure. In case satellite time system status is anomaly, observationTime is corrected by time correction information.

satTime and exposureTime are used for calculation of observationTime. observationTime is expressed as follows:

observationTime
=satTime + (Fixed-delay time) + exposureTime ×0.5
(Fixed-delay time) is a fixed parameter and it is not stored in product.

3.5.4. LineAttribute_1km group

LineAttribute_1km group contains observationTime, etc. for 1 km spatial resolution bands. The contents are the same as LineAttribute_500 group.

3.5.5. ImageData group

ImageData group contains the digital number of CAI-2 data (Effective digit are 12 bits).

Each band includes dark pixels, invalid pixels and valid pixel. The dark pixels are the pixel to store data during dark. The valid pixels are the pixel to store during observing earth surface data. The invalid pixels are not used in processing.

Table 3.5.5-1 shows the pixel number of dark, invalid and valid pixels for each band.

Table 3.5.5-1 Pixel number of Dark, invalid and valid pixels

Band	Number of pixels	Dark pixel No.	Invalid pixel No.	Valid pixel No.
Band1～4 Band 6～9	2056	1～8	-	9～2056
Band 5,10	1024	1～6	7～66	67～1024

3.5.6. GeometryAttribute group

GeometryAttribute group contains information about pixel which has geometry information. The pixels are sampled from reference band every 10 pixels and 10 lines as Figure 3.5.6-1 shows. The reference band is any one of band 1 to 4 in the case of forward looking and any one of band 6 to 9 in the case of backward looking and stdBand shows the band number.

In pixel direction, the pixel are sampled every 10 pixels start from the pixel number 9 to pixel number 2056. The last pixel is 2056.

In line direction, the lines are sampled from the beginning of the lines and every 10 lines. The last line will be a sampled line. Only information of the pixel which has valid orbit data will be stored in the group.

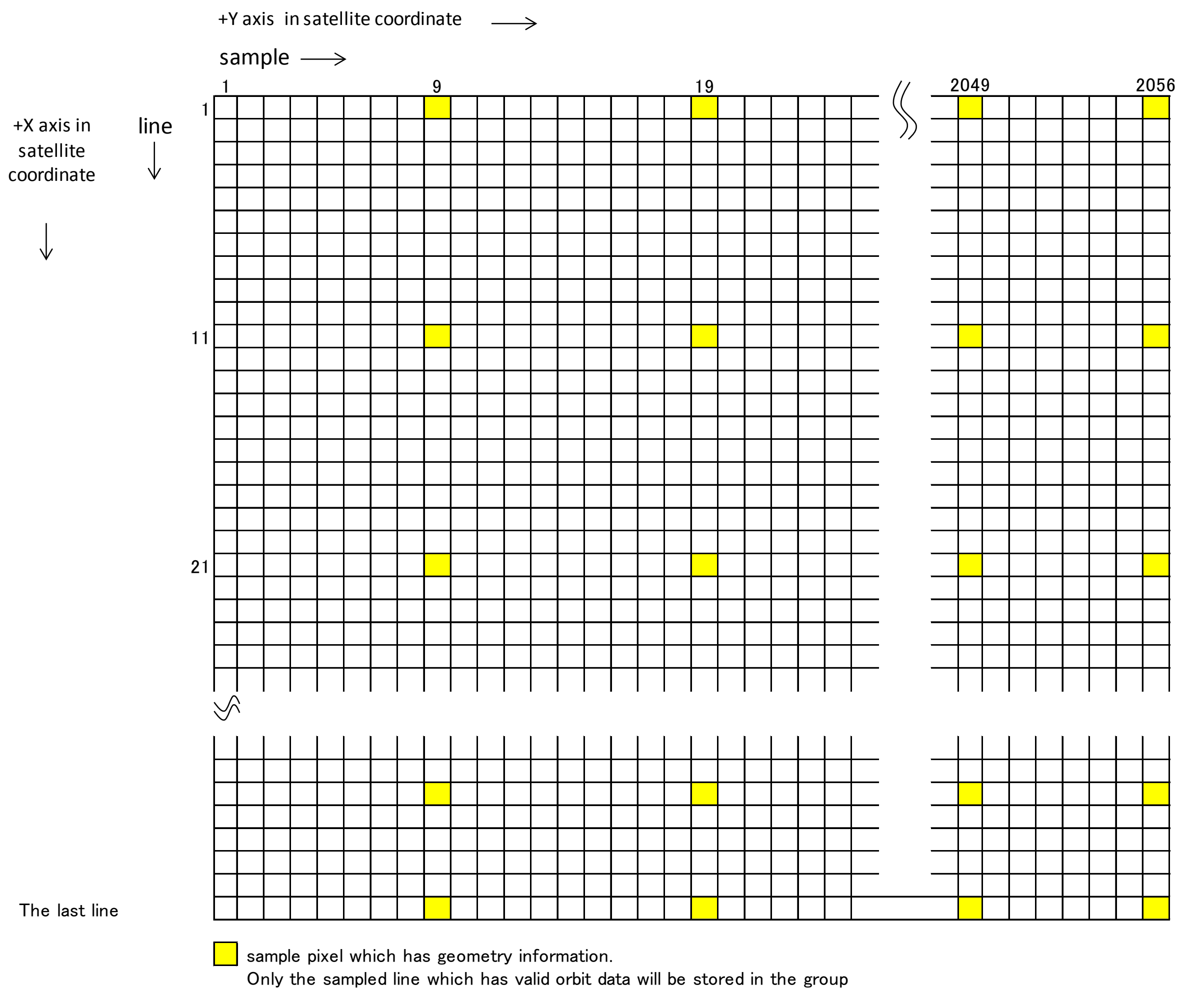

Figure 3.5.6-1 The sample pixels

3.5.7. ImageGeometry group

ImageGeometry group contains latitude and longitude on the standard band image, sensor zenith and azimuth angle, solar zenith and azimuth angle, solar distance from the observation point and lunar to satellite to solar angle.

The calculation of the values in this group related solar position (for example, solar zenith angle, etc.) is used by the apparent position in consideration of light propagation time from sun to earth (fixed value).

The Definition of sensor and solar zenith/azimuth angle and the angle between lunar to satellite vector and solar- to satellite vector in this product are described below.

(1) The Definition of sensor and solar zenith/azimuth angle

When geographic latitude/longitude is defined as λ/φ in observation point $\mathbf{p_{obs}}=(p_{obs\_x}, p_{obs\_y}, p_{obs\_z})^t$, unit vector of zenith direction **z**, unit vector of north direction **n** and unit vector of east direction **e** are expressed as follows:

$$\mathbf{z} = \begin{pmatrix} \cos\varphi\cos\lambda \\ \cos\varphi\sin\lambda \\ \sin\varphi \end{pmatrix} \quad \text{Eq. 3.5.7-1}$$

$$\mathbf{n} = \begin{pmatrix} -\sin\varphi\cos\lambda \\ -\sin\varphi\sin\lambda \\ \cos\varphi \end{pmatrix} \quad \text{Eq. 3.5.7-2}$$

$$\mathbf{e} = \begin{pmatrix} -\sin\lambda \\ \cos\lambda \\ 0 \end{pmatrix} \quad \text{Eq. 3.5.7-3}$$

Using sensor or solar position vector in ECR $\mathbf{p_{ECR}}$, zenith angle θ_z and azimuth angle φ_{Az} are expressed as follows:

$$\theta_z = \mathrm{acos}\left(\frac{(\mathbf{p_{ECR}} - \mathbf{p_{obs}})\cdot\mathbf{z}}{|\mathbf{p_{ECR}} - \mathbf{p_{obs}}|}\right) \quad \text{Eq. 3.5.7-4}$$

$$\varphi_{Az} = \mathrm{atan\,2}\left((\mathbf{p_{ECR}} - \mathbf{p_{obs}})\cdot\mathbf{e},\quad (\mathbf{p_{ECR}} - \mathbf{p_{obs}})\cdot\mathbf{n}\right) \quad \text{Eq. 3.5.7-5}$$

$(\mathbf{p_{ECR}} - \mathbf{p_{obs}})$ is the direction to sun from observation point or satellite.

As the azimuth angle φ_{Az} is defined from 0 to2π [rad] (0 to 360[deg]). If φ_{Az} is negative value at Eq.3.5.7-5 add 2π to φ_{Az}. The definition of atan2 function, please refer to Chapter 5.

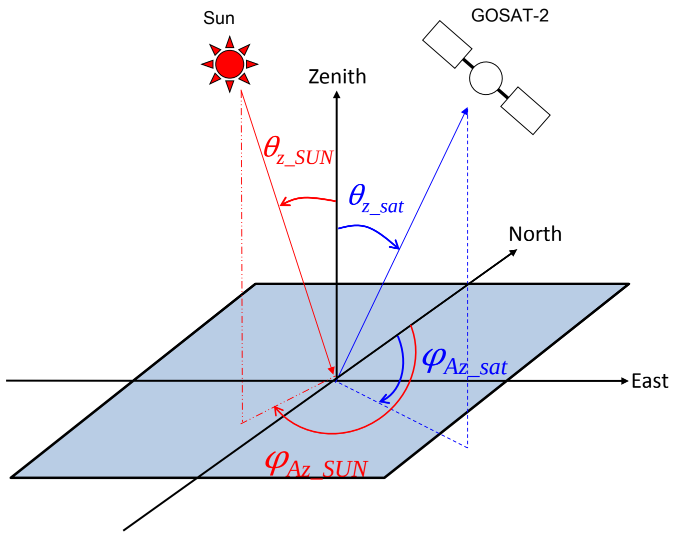

Figure 3.5.7-1 The definition of sensor and solar zenith/azimuth angle.

(2) The Definition of angle between lunar to satellite vector and solar to satellite vector

Using sensor position vector $\mathbf{p}_{\mathbf{sat}}$, solar position vector $\mathbf{p}_{\mathbf{SUN}}$ and lunar position vector $\mathbf{p}_{\mathbf{MOON}}$, the angle between lunar to satellite vector and solar to satellite vector θ_{el} is expressed as follows:

$$\theta_{el} = \mathrm{acos}\left(\frac{(\mathbf{p}_{\mathrm{MOON}} - \mathbf{p}_{\mathrm{sat}}) \cdot (\mathbf{p}_{\mathrm{SUN}} - \mathbf{p}_{\mathrm{sat}})}{|\mathbf{p}_{\mathrm{MOON}} - \mathbf{p}_{\mathrm{sat}}||\mathbf{p}_{\mathrm{SUN}} - \mathbf{p}_{\mathrm{sat}}|} \right) \qquad \text{Eq. 3.5.7-6}$$

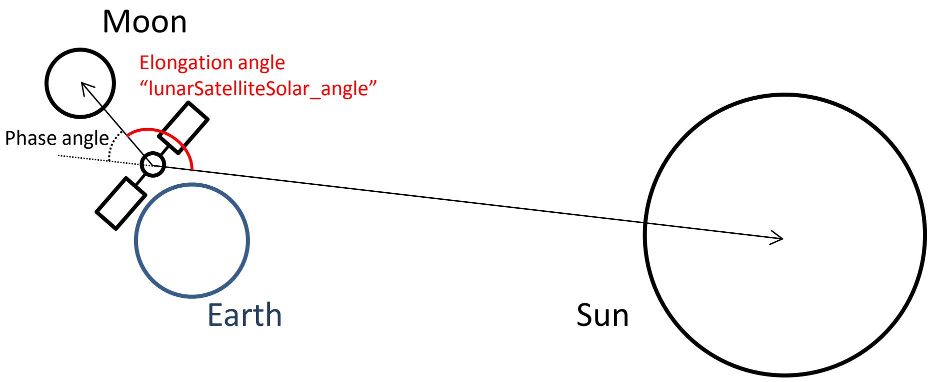

Figure 3.5.7-2 The angle between lunar-satellite vector and solar-satellite vector.

(3) The definition of scatter angle

The scatter angle is defined as the angle between the progress direction of scattered light and the direction of incident light. When the scatted light progresses to the same direction of incident light（φ_{SCAT}=0 degree）, the scatter is called the forward scatter and when it progresses to the opposite direction（φ_{SCAT}=180 degree）, it is called the backward scatter. The definition is as follows.

$$\varphi_{SCAT} = \mathrm{acos}(\Phi_{SCAT}) \qquad \text{Eq. 3.5.7-7}$$

Φ_{SCAT} is defined as follows and others like θ_{z_sat}refers to section(1) and Figure3.5.8-1

$$\begin{aligned}\Phi_{SCAT} = &-\sin\theta_{z\_SUN}\sin\varphi_{Az\_SUN}\sin\theta_{z\_sat}\sin\varphi_{Az\_sat}\\ &-\sin\theta_{z\_SUN}\cos\varphi_{Az\_SUN}\sin\theta_{z\_sat}\cos\varphi_{Az\_sat}\\ &-\cos\theta_{z\_SUN}\cos\theta_{z\_sat}\end{aligned}$$

Eq.3.5.7-8

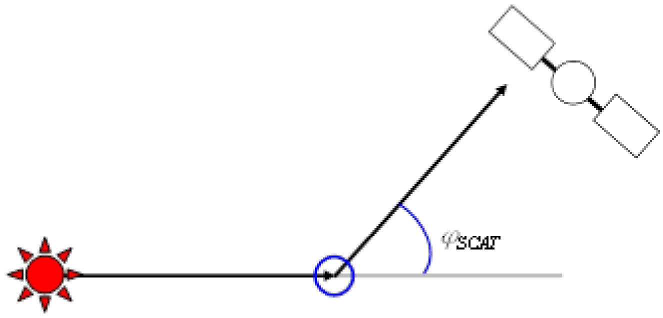

Figure 3.5.7-3 The definition of scattered angle

3.5.8. SatelliteGeometry group

SatelliteGeometry group contains satellite position/velocity (in ECR and TOD) and attitude in the sample lines of standardBand and transformation matrix (satToECR_Matrix) which can convert to ECR (WGS84) coordinate from satellite coordinate.

Satellite attitude is stored as quaternion in J2000.0 and roll, pitch and yaw angles. Definition and usage of quaternion are the same as Chapter 3.4.8. Roll, pitch, and yaw angles are calculated by using quaternion, etc. The algorithm is shown later.

Transformation matrix (satToECR_Matrix) can transform coordinate from satellite coordinate to ECR (WGS84) directly. The matrix includes all coordinate transformation from satellite coordinate to J2000, J2000 to TOD, and TOD to ECR(WGS84). For usage of this matrix, see Chapter 5.

The calculation of roll, pitch and yaw angles are described below.
The first step is to make a transform matrix from orbit coordinate to TOD by using $\mathbf{p}_{\mathbf{TOD}}$ satellite position and velocity $\mathbf{v}_{\mathbf{TOD}}$ vectors in TOD .

$$\mathbf{E}_{\text{orbit-TOD}} = \begin{pmatrix} E_{11} & E_{12} & E_{13} \\ E_{21} & E_{22} & E_{23} \\ E_{31} & E_{32} & E_{33} \end{pmatrix} \quad \text{Eq. 3.5.8-1}$$

Each element of the matrix is defined as follows:

$$\mathbf{E}_{\mathbf{z}} = \begin{pmatrix} E_{13} \\ E_{23} \\ E_{33} \end{pmatrix} = -\frac{\mathbf{p}_{\mathbf{TOD}}}{|\mathbf{p}_{\mathbf{TOD}}|} \quad \text{Eq. 3.5.8-2}$$

$$\mathbf{E}_{\text{y}} = \begin{pmatrix} E_{12} \\ E_{22} \\ E_{32} \end{pmatrix} = -\frac{\mathbf{p}_{\mathbf{TOD}} \otimes \mathbf{v}_{\mathbf{TOD}}}{|\mathbf{p}_{\mathbf{TOD}} \otimes \mathbf{v}_{\mathbf{TOD}}|} \quad \text{Eq. 3.5.8-3}$$

$$\mathbf{E}_{\text{x}} = \begin{pmatrix} E_{11} \\ E_{21} \\ E_{31} \end{pmatrix} = \mathbf{E}_{\text{y}} \otimes \mathbf{E}_{\text{z}} \quad \text{Eq. 3.5.8-4}$$

where $\otimes$ denotes outer product.

Next step is to make a transform matrix from orbit coordinate to satellite body $\mathbf{M_{orbit\text{-}body}}$ by using $\mathbf{E_{orbit\text{-}TOD}}$, quaternion, and PN matrix,

$$\mathbf{M}_{\text{orbit-body}} = \mathbf{M}_{\text{J2000-body}} \times \mathbf{PN}^{t} \times \mathbf{E}_{\text{orbit-TOD}}, \qquad \text{Eq. 3.5.8-5}$$

where the superscript t denotes transpose, and $\mathbf{M_{J2000\text{-}body}}$ is defined by Eq. 3.4.8-1.

The same matrix $\mathbf{M_{J2000\text{-}body}}$ can be defined by roll φ, pitch θ and yaw ψ, where each angle is defined as the rotation (Euler) angle between orbit coordinate and satellite body:

$$\mathbf{M}_{\text{orbit-body}} = \begin{pmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{pmatrix} \begin{pmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \sin\varphi\cos\theta \\ \cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi & \cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi & \cos\varphi\cos\theta \end{pmatrix}$$

Eq. 3.5.8-6

By equation Eq. 3.5.8-5 and Eq. 3.5.8-6, roll φ, pitch θ and yaw ψ can be obtained as follows:

$$\begin{aligned} \varphi &= \operatorname{atan2}(M_{23}, M_{33}) \\ \theta &= \operatorname{asin}(-M_{13}) \\ \psi &= \operatorname{atan2}(M_{12}, M_{11}) \end{aligned} \qquad \text{Eq. 3.5.8-7}$$

3.5.9. SolarGeometry group

SolarGeometry group contains apparent solar position and velocity (in ECR and TOD) in the sample lines of standardBand. The values take account of the light propagation time from sun to earth (8 minutes 19 seconds/ fixed value/ specified by parameters).

3.5.10. LunarGeometry group

LunarGeometry group contains true lunar position and velocity (in ECR and TOD) in the sample lines of standard band.

4. Image Processing

This chapter describes how to convert the digital number stored in ImageData group to the luminance with band-to-band registration

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4.1. Processing flow

4.1.1. Band 2,3,4,7,8 and 9

Figure 4-1 shows the image processing for band 2,3,4,7,8 and 9.

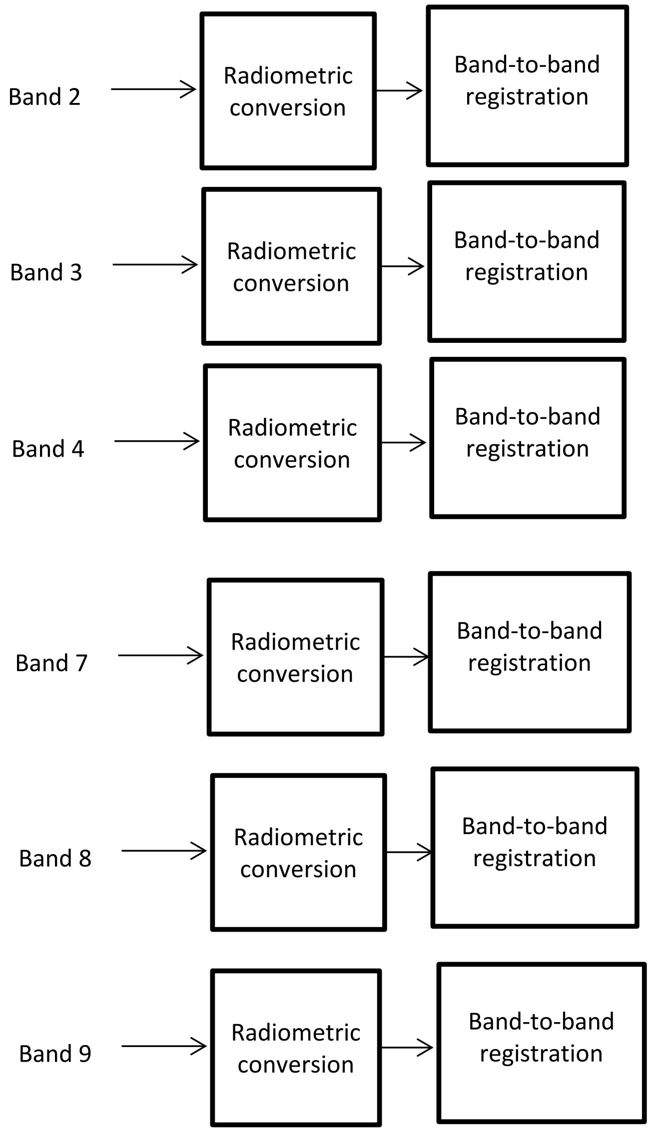


Figure 4-1 Image processing for Band 2,3,4,7,8 and 9

The image is processed in following steps.

Radiometric conversion	Convert 12bit observation data to the luminance (W/m^2/μ m/str). Refer to section 4.2.
Band-to-band registration	Transform the image to be overlaid on the base band. Refer to section 4.3

4.1.1. Band 1,6

Figure 4-2 shows the image processing for band 1 and 6.

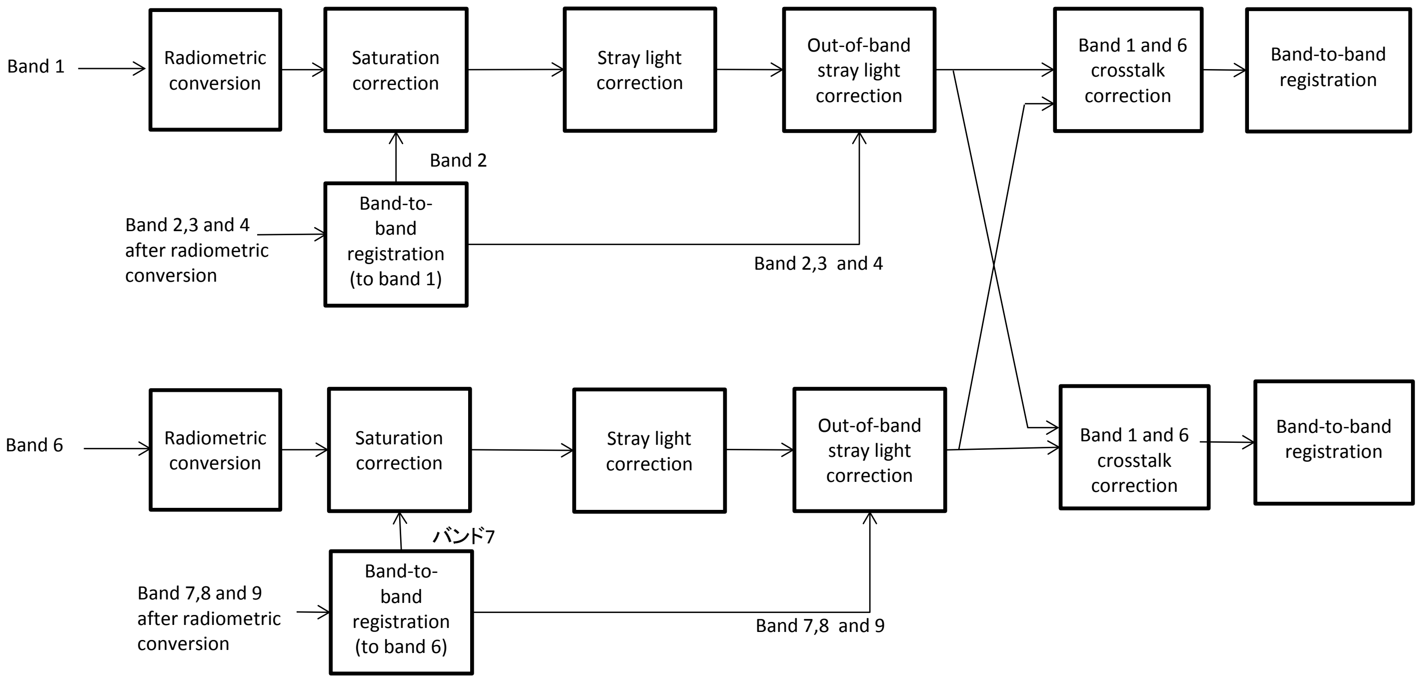


Figure 4-2 Image processing for Band 1 and 6

The image is processed in following steps.

Radiometric conversion	Convert 12bit observation data to the luminance ($W/m^2/\mu m/str$). Refer to section 4.2.
Saturation correction	Correct saturated pixel value with the estimated value of around corresponding pixel of band 2,7. Refer to section 4.3.
Stray light correction	Correct stray light in 1 or 6 band. Refer to section 4.5.
Out-of-band stray light correction	Correct out-of-band stray light from band 2,3,4 or 7,8,9. Refer to section 4.6.
Band 1 and 6 crosstalk correction	Correct crosstalk between band 1 and band 6. Refer to section 4.7.
Band-to–band Registration	Transform the image to be overlaid on the base band. Refer to section 4.3.

4.1.1. Band 5,10

Figure 4-3 shows the image processing for band 5 and 10.

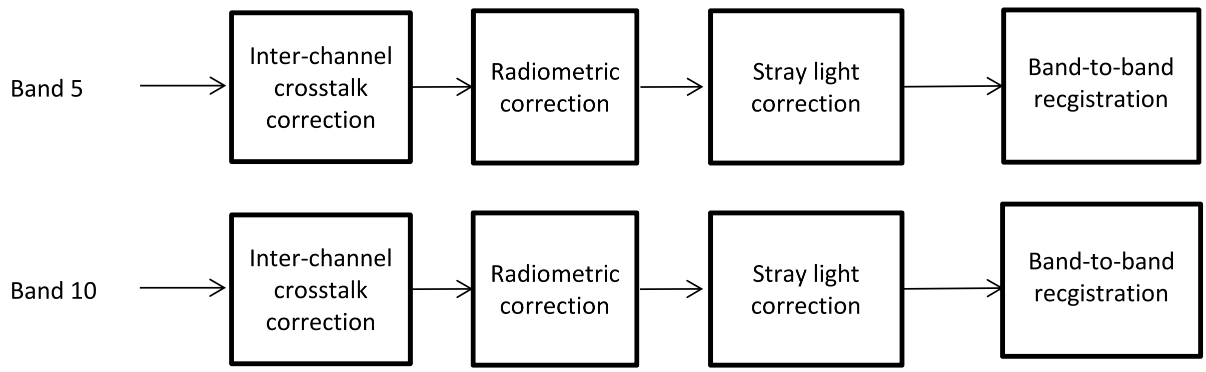


Figure 4-3 Image processing for Band 5 and 10

The image is processed in following steps.

Inter-channel crosstalk correction	Correct inter-channel crosstalk within the band. Refer to section 4.8.
Radiometric conversion	Convert 12bit observation data to the luminance (W/m^2/μ m/str). Refer to section 4.2.
Stray light correction	Correct stray light in band5 or band10. Refer to section 4.9.
Band-to-band registration	Transform the image to be overlaid on the base band. Refer to section 4.3.

4.2. Radiometric conversion

Radiometric conversion method calculating from the digital values, DN to the brightness (W/m²/μm/str) is described below. In follows, temperatures are expressed in degrees Celsius.

(1) Correction of the DN value for valid pixels using pre-amplifier temperature T_1 and amplifier temperature T_2

The DN value of valid pixels $X(m,n.l)$ are corrected with pre-amplifier temperature T_1 and amplifier temperature T_2 .

$$Z_1(m,n,l) = \frac{X(m,n,l)}{C_1(m,T_1(m,l))\,C_2(m,T_1(m,l))} \quad \text{Eq. 4-1}$$

m, n and l are band number, pixel number and line number, respectively.

The coefficient C_1 and C_2 is calculated as follows:

$$C_1(m,T_1(m,l)) = \sum_{k=0}^{3} a(m,k)T_1^k(m,l) \quad \text{Eq. 4-2}$$

$$C_2(m,T_2(m,l)) = \sum_{k=0}^{3} b(m,k)T_2^k(m,l) \quad \text{Eq. 4-3}$$

Pre-amplifier temperature T_1 and amplifier temperature T_2 are stored in TemperatureTelemetry_1sec group of Common file. The coefficients of polynomial a and b are unique to each band. These are provided in separate file.

(2) The correction term Z_{21} calculated by dark pixel

The correction term Z_{21} can be calculated with average of dark pixels X_{dk1}, pre-amplifier temperature T_1 and amplifier temperature T_2.

$$Z_{21\_ODD}(m,n,l) = \frac{X_{dk1\_ODD}(m,l)}{C_1(m,T_1(m,l))\,C_2(m,T_2(m,l))} \quad if\ m \neq 5,10\ and\ n = 2k-1\ (k=1,2,...)$$

$$Z_{21\_EVEN}(m,n,l) = \frac{X_{dk1\_EVEN}(m,l)}{C_1(m,T_1(m,l))\,C_2(m,T_2(m,l))} \quad if\ m \neq 5,10\ and\ n = 2k\ (k=1,2,...)$$

$$Z_{21}(m,n,l) = \frac{X_{dk1}(m,l)}{C_1(m,T_1(m,l))\,C_2(m,T_2(m,l))} \quad if\ m = 5,10$$

Eq. 4-4

Here m, n and l are band number, pixel number and line number, respectively.

$X_{dk1\_ODD}(m,l)$ is the average of up to 4 dark pixels selected from pixel number1,3,5,7 in the l' $(l - pw \leq l' \leq l + pw$、$pw$ is the parameter) near line l .

$X_{dk1_EVEN}(m,l)$is the average of up to 4 dark pixels selected from pixel number2,4,6,8 in the l' $(l - pw \leq l' \leq l + pw$、$pw$ is the parameter) near line l .

X_{dkl} is the average of up to 6 dark pixels selected from pixel number1 to 6 in the l' $(l - pw \leq l' \leq l + pw$、$pw$ is the parameter) near line l .

The coefficient C_1 and C_2 are the same as Eq. 4-2 and 4-3.

(3) The correction term of Z_{22} calculated by dark earth observation data, pixel temperature T_3 and exposure duration time t_{int}.

The correction term Z_{22} can be calculated using the night observation data (the average of time series of X_{dk2} (m, n), pre-amplifier temperature $T'_1(m)$, amplifier temperature $T'_2(m)$ and pixel temperature $T'_3(m)$ and the exposure time $t_{int.}$ (m, l)) band m, and exposure time t_{int} (m,l) at line l.

$$
Z_{22}(m,n,l) = \begin{cases}
\left(X_{dk2}(m,n) - X_{dk3\_ODD}(m)\right) \times \dfrac{C_3(m,n,T_3'(m))\,C_4(m,t_{int}(m,l),t_{int}'(m))}{C_1(m,T_1'(m))\,C_2(m,T_2'(m))} & if\ m \neq 5,10\ and\ n = 2k-1\ (k=1,2...) \\
\left(X_{dk2}(m,n) - X_{dk3\_EVEN}(m)\right) \times \dfrac{C_3(m,n,T_3'(m))\,C_4(m,t_{int}(m,l),t_{int}'(m))}{C_1(m,T_1'(m))\,C_2(m,T_2'(m))} & if\ m \neq 5,10\ and\ n = 2k\ (k=1,2...) \\
\left(X_{dk2}(m,n) - X_{dk3}(m)\right) \times \dfrac{C_3(m,n,T_3'(m))\,C_4(m,t_{int}(m,l),t_{int}'(m))}{C_1(m,T_1'(m))\,C_2(m,T_2'(m))} & if\ m = 5,10
\end{cases}
$$

Eq. 4-5

Here m, n and l are band number, pixel number and line number, respectively.
$X_{dk3\_ODD}(m)$:X_{dk2} is the average of up to 4 dark pixels selected from pixel X_{dk2} number1,3,5,7.
$X_{dk3\_EVEN}(m)$:X_{dk2} is the average of up to 4 dark pixels selected from pixel X_{dk2} number2,4,6,8.
$X_{dk3}(m)$:X_{dk2} is the average of up to 6 dark pixels selected from pixel X_{dk2} number1 to 6.
X_{dk2} is provided as the parameter file.

The coefficient C_1 and C_2 is calculated by substituting temperatures of pre amplifier T'_1、T'_2 into Eq.4-2, and Eq.4-3 at the acquisition of X_{dk2}. T'_1、T'_2 are provided together with X_{dk2}.

The coefficient C_3 and C_4 can be calculated as follows:

$$C_3(m,n,T_3'(m)) = \sum_{k=0}^{3} c(m,n,k)T_3'^k(m) \quad \text{Eq. 4-6}$$

$$C_4(m,t_{\text{int}}(m,l),t_{\text{int}}'(m)) = \sum_{k=0}^{3} d(m,k)\left(\frac{t_{\text{int}}(m,l)}{t_{\text{int}}'(m)}\right)^k \quad \text{Eq. 4-7}$$

Here T_3' is the pixel temperature at the acquisition of X_{dk2} and is provided together with X_{dk2}.

Exposure time t_{int} (ms) is stored for each line in LineAttribute group of forward/backward looking band file. t'_{int}(ms) is the integration time at the acquisition of X_{dk2} and provide together with X_{dk2}.
The coefficients of polynomial c and d are provided as the parameter file.

(4) The calculation of corrected pixel digital value Z

The corrected pixel digital value Z can be calculated with Z_1, Z_{21} and Z_{22} which are defined in above (1) to (3),

$$Z(m,n,l) = \begin{cases} Z_1(m,n,l) - Z_{21\_ODD}(m,n,l) - Z_{22\_ODD}(m,n,l) & if\ m \neq 5,10\ and\ n = 2k-1\ (k=1,2...) \\ Z_1(m,n,l) - Z_{21\_EVEN}(m,n,l) - Z_{22\_EVEN}(m,n,l) & if\ m \neq 5,10\ and\ n = 2k\ (k=1,2...) \\ Z_1(m,n,l) - Z_{21}(m,n,l) - Z_{22}(m,n,l) & if\ m = 5,10 \end{cases}$$ Eq. 4-8

(5) Conversion to radiance *Rad*

The conversion from the corrected pixel digital value Z to radiance *Rad* [W/m²/μm/str] is expressed as follows:

$$Rad(m,n,l) = R(m,n,0) + \frac{1}{C_5(m,t_{\text{int}}(m,l))C_6(m,T_3(m,l))}\sum_{k=1}^{3} R(m,n,k)Z^k(m,n,l)$$

Eq. 4-9

The coefficients C_5 and C_6 are calculated as follows:

$$C_5(m,t_{\text{int}}(m,l)) = \sum_{k=0}^{3} e(m,k)t_{\text{int}}^k(m,l)$$ Eq. 4-10

$$C_6(m,T_3(m,l)) = \sum_{k=0}^{3} f(m,k)T_3^k(m,l)$$ Eq. 4-11

The pixel temperature is stored in the TemperatureTelemetry_1sec group in the common file. The polynominal coeffficent *e*, *f* and *R*(*m*,*n*,*k*) are provided as the parameter file.

Basically *R(m,n,k)* is constant value because is calculated from sensor gain and the sensor gain will not be changed in space . If sensor gain was changed for some reason, the *R(m,n,k)* parameter file will be updated and the provided.

4.3. Band-to-band registration

Because the view area of the band is slightly different each other, we transform images by pre-calculated lookup table to be overlaid on the base band. The following equation shows the transformation.

$$IMG_{i,B}(n,l) = IMG_i(n'_B(i,n),\ l'_B(i,n,l)) \qquad \text{Eq. 4.3-1}$$

Where

$IMG_{i,B}(n,l)$: The image data of band *i overlaid* on the band *B* (pixel *n*, line *l*)

$IMG_i(u,v)$: The image data of band *i* (pixel *u*, line *v*)

$n'_B(i,n)$: The pixel number of band *i* corresponding to the band *B* pixel *n*

$l'_B(i,n,l)$: The line number of band *i* corresponding to the band *B* pixel *n* line *l*

Figure 4-4 shows the example of the band-to-band registration.

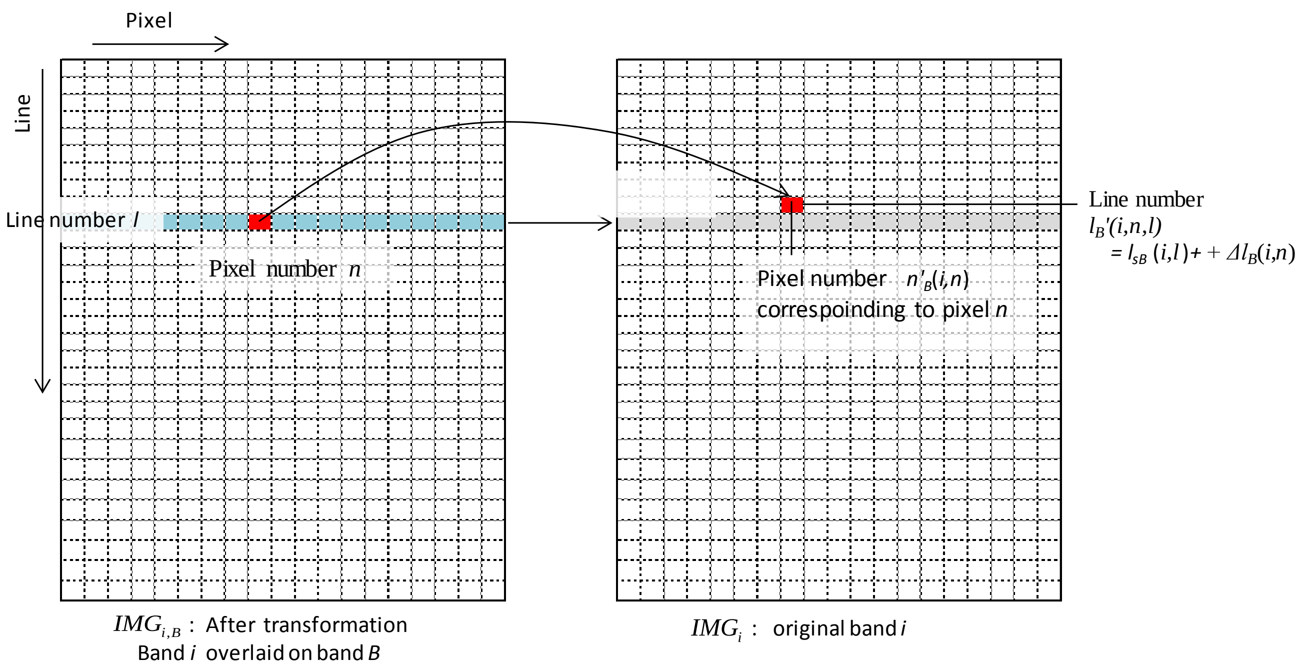


Figure 4-4 Band-to-band registration

$n'_B(i,n)$ is lookup table in the parameter file..

$l'_B(i,n,l)$ is defined by following equation.

$$l'_B(i,n,l) = l_{sB}(i,l) + \Delta l_B(i,n) \qquad \text{Eq. 4.3-2}$$

Where

$l_{sB}(i,l)$: The line number which was observed at the nearest observation time to band B

line *l*.

$\Delta l_B(i,n)$: The error of line number of band *i*.

$\Delta l_B(i,n)$ is lookup table in the parameter file..

4.4. Saturation correction

The observation data is 12bit digital number (DN) so it will be saturated with 4095. For band1 and 6, the value before saturation is estimated using pixels around the saturated pixel and other bands. The following equations show the saturation correction.

Band 1

$$IMG_1(n,l) = A_{1,2}(n,l) \cdot IMG_2(n,l) \qquad \text{Eq.4.4-1}$$

Band 6

$$IMG_6(n,l) = A_{6,7}(n,l) \cdot IMG_7(n,l) \qquad \text{Eq.4.4-2}$$

Where

$IMG_i(n,l)$: The luminance image data of band *i*(*i=1,6*) (pixel *n*, line *l*)

$A_{i,r}(n,l)$: The coefficient for band *i* (pixel *n,* line *l*), predicted by band *r.*

Figure 4-5 shows the saturation correction (example of band1)

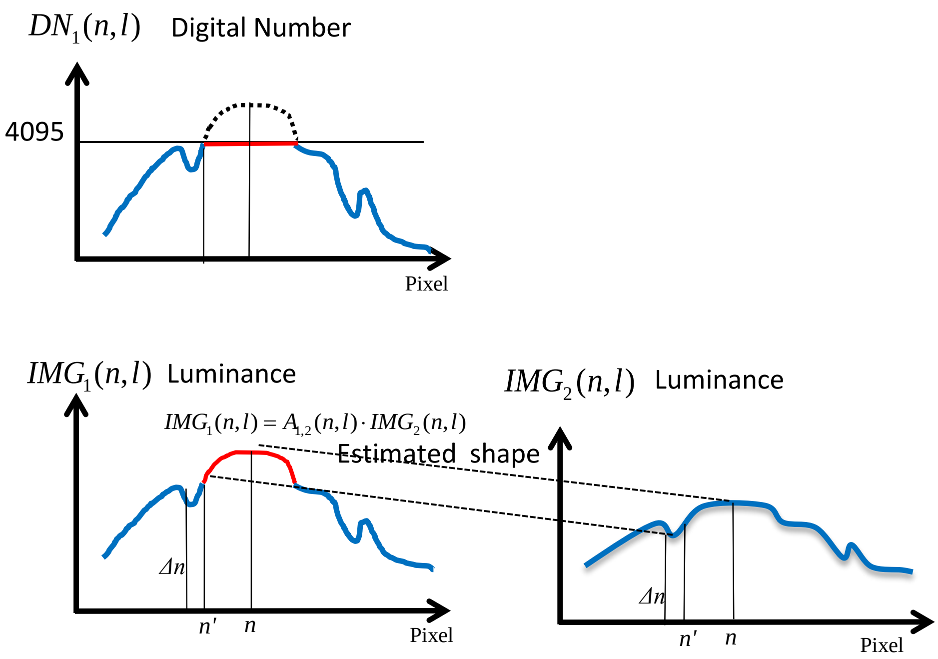


Figure 4-5 Example of saturation correction (in case of band1)

$A_{i,r}(n,l)$ is defined as the following average value of IMG_i / IMG_r around the saturated pixel n. Where n' is the unsaturated nearest neighbor of the saturated pixel n.

$$A_{i,r}(n,l) = \frac{1}{N} \sum_{v=l-\Delta l}^{l+\Delta l} \sum_{u=n'_{\min}}^{n'_{\max}} \frac{IMG_i(u,v)}{IMG_r(u,v)} \qquad \text{Eq. 4.4-3}$$

$$n'_{\min} = \begin{cases} n' - \Delta n & \text{if } n' < n \\ n' & otherwise \end{cases} \qquad \text{Eq.4.4-4}$$

$$n'_{\max} = \begin{cases} n' & \text{if } n' < n \\ n' + \Delta n & otherwise \end{cases} \qquad \text{Eq.4.4-5}$$

$$N = (2\Delta l + 1)(\Delta n + 1) \qquad \text{Eq.4.4-6}$$

The both Δn and Δl are parameters which mean the range to calculate $A_{i,r}(n,l)$.

No correction will be applied for *IMG*(n,l),when data is missing or *IMG*(n,l) is 0.

4.5. Stray light correction for band 1 and 6

The observation data of band 1 and band6 are contaminated by stray light component. We estimate the stray light component by the convolution of observation data and "Point Spread Function (PSF)", and remove it from the observation data.

The following equations show the stray light correction for band 1 and 6.

Band 1

$$IMG_1(n,l) = A_1(n)(IMG_1(n,l) - H_{1,a}(u,v) \otimes IMG_1(n,l)) \quad \text{Eq.4.5-1}$$

Band 6

$$IMG_6(n,l) = A_6(n)(IMG_6(n,l) - H_{6,a}(u,v) \otimes IMG_6(n,l)) \quad \text{Eq.4.5-2}$$

Where

$IMG_i(n,l)$: The luminance image data of band i(i=1,6) (pixel n, line l)

$H_{i,a}(u,v)$: The stray light PSF for band1 i(i=1,6) (pixel u, line v)

$\otimes$: The convolution operator

$A_i(n)$: The coefficient to correct signal reduction by subtraction of the stray light component. (Pixel n)

Figure 4-6 shows the example of stray light correction.

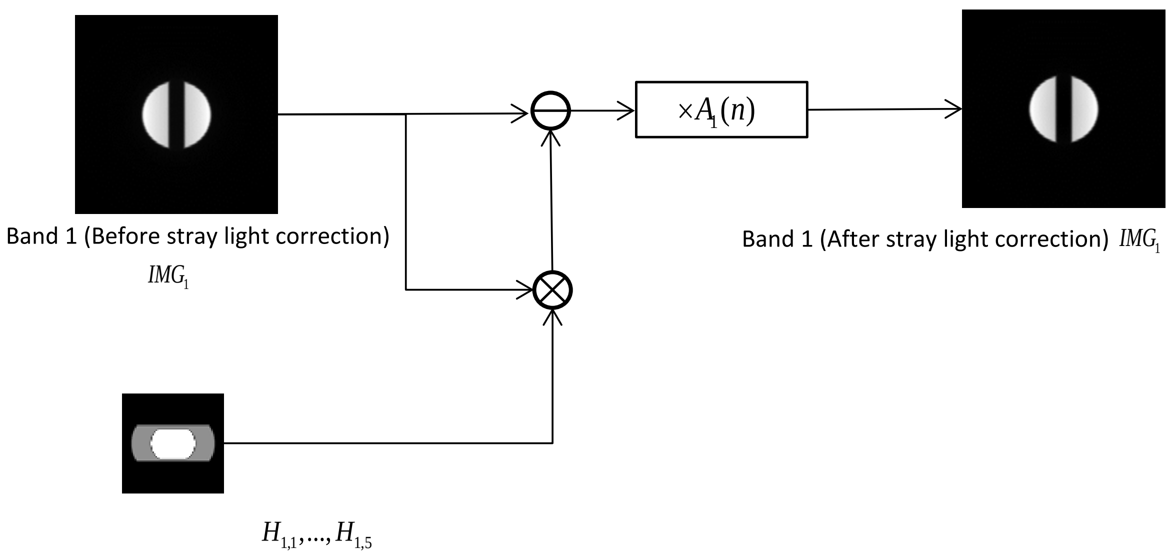


Figure 4-6 Stray light correction (example of band1)

Because stray light depends on the pixel position in image, we use five PSF $H_{i,a}(u,v)$ from $H_{i,1}(u,v)$ to $H_{i,5}(u,v)$ for the correction. Figure 4-7 shows example of PSF and applying area.

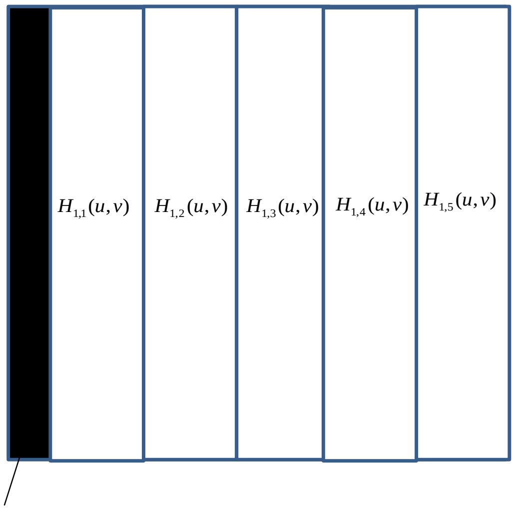


Figure 4-7　PSF and applying area (example of band1)

$H_{i,a}(u,v)$ and the applying area is defined in the parameter file.

PSF applying area is defined within the valid pixel area. We apply the border processing to out of the valid pixel area. The border processing is described in section 4.11.

Before the convolution, the missing line in $IMG_i(n,l)$ must be filled by the interpolation.

The interpolation is described in section 4.10.

$A_i(n)$ is the coefficient in the parameter file.

4.6. Out-of-band stray light correction for band 1 and 6

The observation data of band 1 and band6 also are contaminated with stray light component coming from out-of-band. As same as section 4.5, we calculate the stray light component by the convolution of observation data and PSF, and remove it from the observation data.

The following equations show the out-of-band stray light correction for band 1 and 6.

Band 1

$$IMG_1(n,l) = IMG_1(n,l) - \sum_{j=2,3,4} H_{1,j}(u,v) \otimes IMG_j(n,l) \qquad \text{Eq. 4.6-1}$$

Band 6

$$IMG_6(n,l) = IMG_6(n,l) - \sum_{j=7,8,9} H_{6,j}(u,v) \otimes IMG_j(n,l) \qquad \text{Eq. 4.6-2}$$

Where

$IMG_i(n,l)$: The luminance image data of band i(i=1,2,3,4,6,7,8,9) (pixel n, line l)

$H_{i,j}(u,v)$: The band j (j=2,3,4,7,8,9) out-band-stray light PSF for band i(i=1,6) (pixel u, line v)

$\otimes$: The convolution operator

Figure 4-8 shows the out-of-band stray light correction.

PSF applying area is defined within the valid pixel area. We apply the border processing to out of the valid pixel area. The border processing is described in section 4.11.

Before the convolution, the missing line in $IMG_j(n,l)$ (j=2,3,4,7,8,9) must be filled by the interpolation. The interpolation is described in section 4.10.

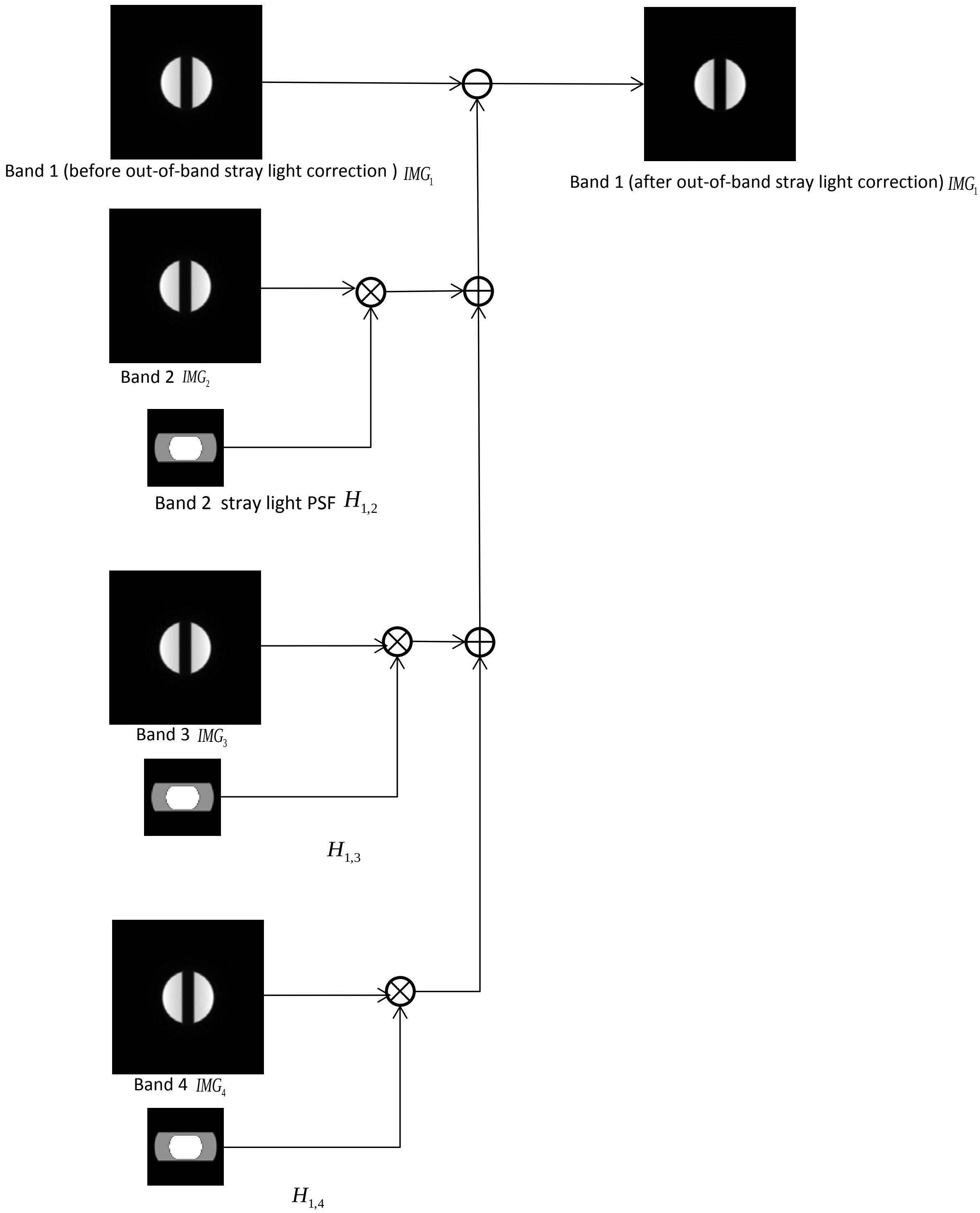


Figure 4-8 Out-of-band stray light correction (example of band1)

4.7. Band 1 and 6 crosstalk correction

The observation data of band 1 and band6 also are contaminated with crosstalk of each other. As same as section 4.5, we calculate the crosstalk component by the convolution of observation data and PSF, and remove it from the observation data.

The following equations show the band 1 and 6 crosstalk correction.

Band 1

$$IMG_1(n,l) = IMG_1(n,l) - H_6(u,v) \otimes IMG_{6,1}(n,l) \qquad \text{Eq. 4.7-1}$$

Band 6

$$IMG_6(n,l) = IMG_6(n,l) - H_1(u,v) \otimes IMG_{1,6}(n,l) \qquad \text{Eq. 4.7-2}$$

Where

$IMG_i(n,l)$: The luminance image data of band i(i=1,6) (pixel n, line l)

$IMG_{r,i}(n,l)$: The luminance image data of band r(r=1,6) which is extracted by observation time of band i

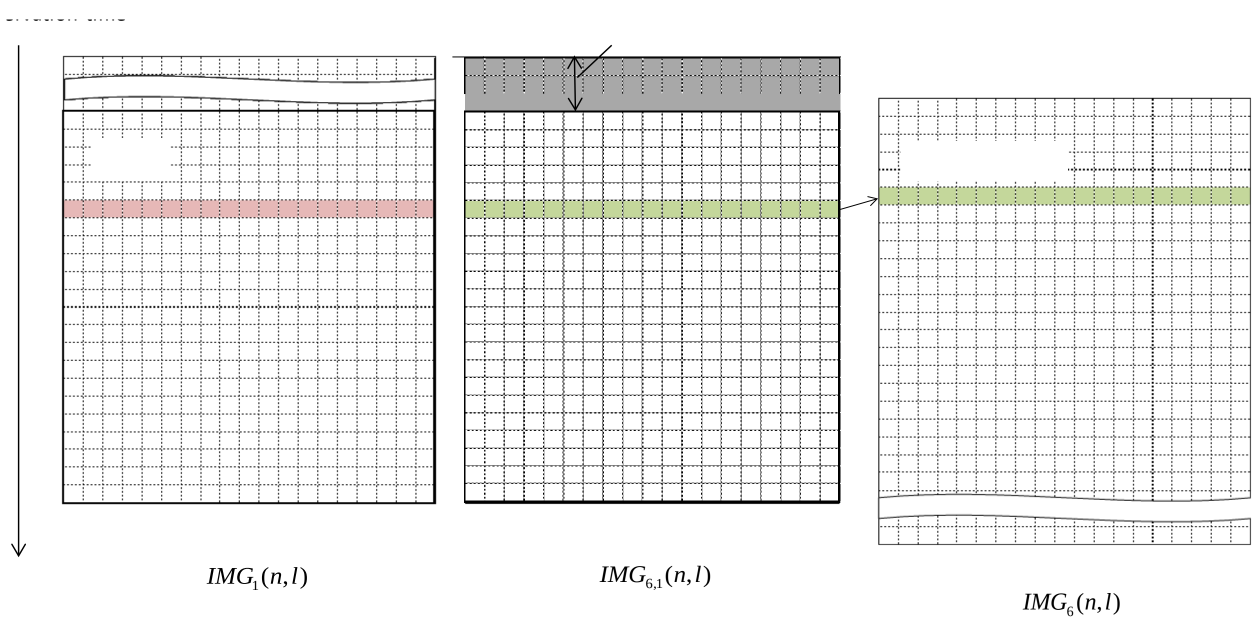
$H_i(u,v)$: The band i(i=1,6) crosstalk PSF

$\otimes$: The convolution operator

Figure 4-9 shows the example of the band-to-band registration for crosstalk correction between band 1 and 6. For each line of band i, $IMG_{r,i}(n,l)$ is defined by the band r which observation time is nearest time to band i. If the time difference between band i line l and the its nearest line of band r is greater than the double of nominal observation cycle, we assume the line of $IMG_i(n,l)$ is a missing line. Before the convolution, the missing line in $IMG_{r,i}(n,l)$ must be filled by the interpolation. The interpolation is described in section 4.10.

Only forward or backward looking data are filled with 0 in $IMG_{r,i}(n,l)$

PSF applying area is defined in the valid pixel area. We apply the border processing to out of the valid pixel area. The border processing is described in section 4.11.



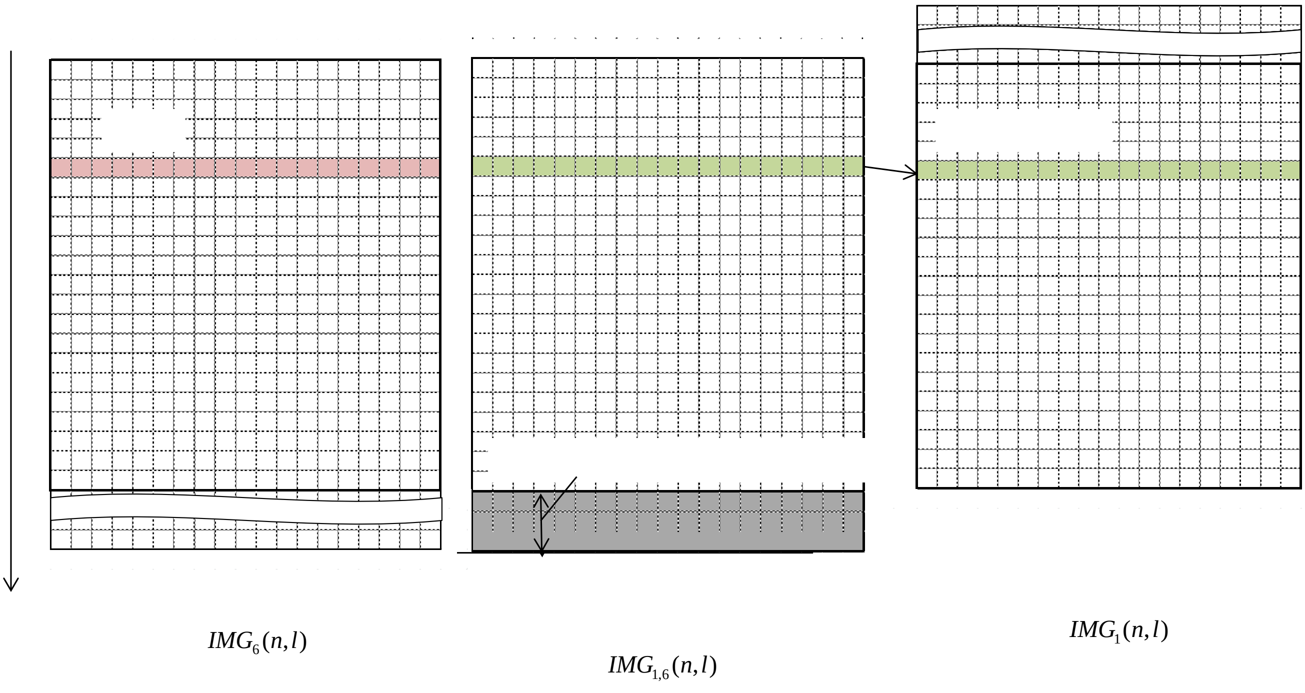


Figure 4-9 Band-to-band registration for band 1 and 6 crosstalk correction.

4.8. Inter-channel crosstalk correction for band 5 and 10

The observation data of band 5 and band10 are contaminated with the electrical inter-channel crosstalk
between the data reading channels (CH). Figure 4-10 shows the relation of pixels and channels. Figure 4-11 shows the example of inter-channel crosstalk.

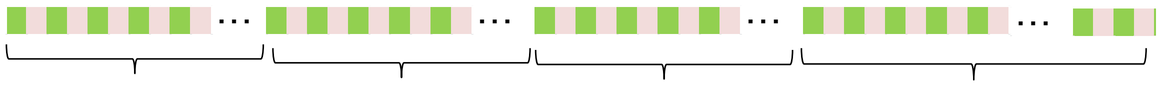


Figure 4-10 Band 5 and 10 pixels and channels

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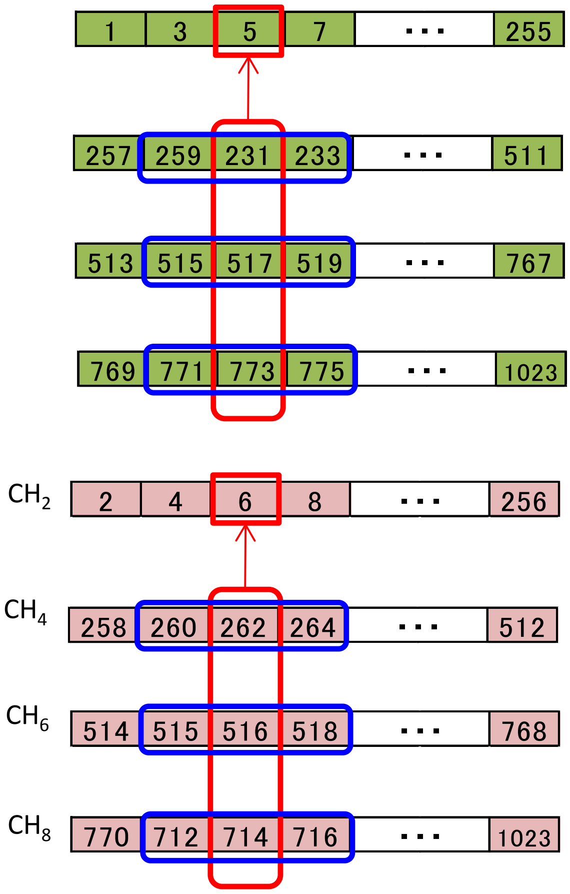

Figure 4-11 Explanation of inter-channel crosstalk (Example, CH1 and CH2)

Following equation shows to remove the crosstalk component.

Where $CH_i(n,l)$ is the observation data as the digital number of band *i* pixel *n*, line *l*.

$$CH_1(n_1,l) = CH_1(n_1,l) - \left(a_{31} \times CH_3(n_3,l) + a_{51} \times CH_5(n_5,l) + a_{71} \times CH_7(n_7,l)\right) - \left(b_{31} \times \left|\frac{\partial CH_3(n_3,l)}{\partial n}\right| + b_{51} \times \left|\frac{\partial CH_5(n_5,l)}{\partial n}\right| + b_{71} \times \left|\frac{\partial CH_7(n_7,l)}{\partial n}\right|\right)$$

Eq. 4.8-1

$$CH_3(n_3,l) = CH_3(n_3,l) - \left(a_{13} \times CH_1(n_1,l) + a_{53} \times CH_5(n_5,l) + a_{73} \times CH_7(n_7,l)\right) - \left(b_{13} \times \left|\frac{\partial CH_1(n_1,l)}{\partial n}\right| + b_{53} \times \left|\frac{\partial CH_5(n_5,l)}{\partial n}\right| + b_{73} \times \left|\frac{\partial CH_7(n_7,l)}{\partial n}\right|\right)$$

Eq. 4.8-2

$$CH_5(n_5,l) = CH_5(n_5,l) - \left(a_{15} \times CH_1(n_1,l) + a_{35} \times CH_3(n_3,l) + a_{75} \times CH_7(n_7,l)\right) - \left(b_{15} \times \left|\frac{\partial CH_1(n_1,l)}{\partial n}\right| + b_{35} \times \left|\frac{\partial CH_3(n_3,l)}{\partial n}\right| + b_{75} \times \left|\frac{\partial CH_7(n_7,l)}{\partial n}\right|\right)$$

Eq. 4.8-3

$$CH_7(n_7,l) = CH_7(n_7,l) - \left(a_{17} \times CH_1(n_1,l) + a_{37} \times CH_3(n_3,l) + a_{57} \times CH_5(n_5,l)\right) - \left(b_{17} \times \left|\frac{\partial CH_1(n_1,l)}{\partial n}\right| + b_{37} \times \left|\frac{\partial CH_3(n_3,l)}{\partial n}\right| + b_{57} \times \left|\frac{\partial CH_5(n_5,l)}{\partial n}\right|\right)$$

Eq. 4.8-4

$$\begin{aligned} n_1 &= 2m+1 && (n_1 = 1,3,5,\ldots,255) \\ n_3 &= 256+2m+1 && (n_3 = 257,259,261,\ldots,511) \\ n_5 &= 512+2m+1 && (n_5 = 513,515,517,\ldots,767) \\ n_7 &= 768+2m+1 && (n_7 = 769,711,713,..,1023) \\ & (0 \le m < 128) \end{aligned}$$

Eq. 4.8-5

$$CH_2(n_2,l) = CH_2(n_2,l) - \left(a_{42} \times CH_4(n_4,l) + a_{62} \times CH_6(n_6,l) + a_{82} \times CH_8(n_8,l)\right) - \left(b_{42} \times \left|\frac{\partial CH_4(n_4,l)}{\partial n}\right| + b_{62} \times \left|\frac{\partial CH_6(n_6,l)}{\partial n}\right| + b_{82} \times \left|\frac{\partial CH_8(n_8,l)}{\partial n}\right|\right)$$

Eq. 4.8-6

$$CH_4(n_4,l) = CH_4(n_4,l) - \left(a_{24} \times CH_2(n_2,l) + a_{64} \times CH_6(n_6,l) + a_{84} \times CH_8(n_8,l)\right) - \left(b_{24} \times \left|\frac{\partial CH_2(n_2,l)}{\partial n}\right| + b_{64} \times \left|\frac{\partial CH_6(n_6,l)}{\partial n}\right| + b_{84} \times \left|\frac{\partial CH_8(n_8,l)}{\partial n}\right|\right)$$

Eq.4.8-7

$$CH_6(n_6,l) = CH_6(n_6,l) - \left(a_{26} \times CH_2(n_2,l) + a_{46} \times CH_4(n_4,l) + a_{86} \times CH_8(n_8,l)\right) - \left(b_{26} \times \left|\frac{\partial CH_2(n_2,l)}{\partial n}\right| + b_{46} \times \left|\frac{\partial CH_4(n_4,l)}{\partial n}\right| + b_{86} \times \left|\frac{\partial CH_8(n_8,l)}{\partial n}\right|\right)$$

Eq.4.8-8

$$CH_8(n_8,l) = CH_8(n_8,l) - \left(a_{28} \times CH_2(n_2,l) + a_{48} \times CH_4(n_4,l) + a_{68} \times CH_6(n_6,l)\right) - \left(b_{28} \times \left|\frac{\partial CH_2(n_2,l)}{\partial n}\right| + b_{48} \times \left|\frac{\partial CH_4(n_4,l)}{\partial n}\right| + b_{68} \times \left|\frac{\partial CH_6(n_6,l)}{\partial n}\right|\right)$$

Eq.4.8-9

$$\begin{aligned} n_2 &= 2m+2 && (n_2 = 2,4,6,...,256) \\ n_4 &= 256+2m+2 && (n_4 = 258,260,262,...,512) \\ n_6 &= 512+2m+2 && (n_6 = 514,516,518,...,768) \\ n_8 &= 768+2m+2 && (n_8 = 770,712,714,..,1024) \\ &(0 \le m < 128) \end{aligned}$$

Eq. 4.8-10

The coefficients a and b are defined in the parameter file.

$\partial CH_i(n,l)/\partial n$ is defined in following equation.

$$\frac{\partial CH_i(n,l)}{\partial n} = \begin{cases} CH_i(n+2,l) - CH_i(n-2,l) & \text{if } 0 < n-2 \text{ and } n+2 \le 1024 \\ 0 & \text{otherwise} \end{cases}$$

Eq. 4.8-11

4.9. Stray light correction for band 5 and 10

The observation data of band 5 and band10 are also contaminated with stray light component. As same as section 4.5, we estimate the stray light component by the convolution of observation data and PSF, and remove it from the observation data.

The following equation shows the stray light correction for band 5 and 10.

Band 5

$$IMG_5(n,l) = A_5(n)(IMG_5(n,l) - H_{5,a}(u,v) \otimes IMG_5(n,l)) \qquad \text{Eq. 4.9-1}$$

Band 10

$$IMG_{10}(n,l) = A_{10}(n)(IMG_{10}(n,l) - H_{10,a}(u,v) \otimes IMG_{10}(n,l)) \qquad \text{Eq. 4.9-2}$$

Where

$IMG_i(n,l)$: The luminance image data of band i(i=5,10) (pixel n, line l)

$H_{i,a}(u,v)$: The stray light PSF for band1 i(i=5,10) (pixel u, line v)

$\otimes$: The convolution operator

$A_i(n)$: The coefficient to correct signal reduction by subtraction of the stray light component.

Figure 4-12 shows the example of stray light correction.

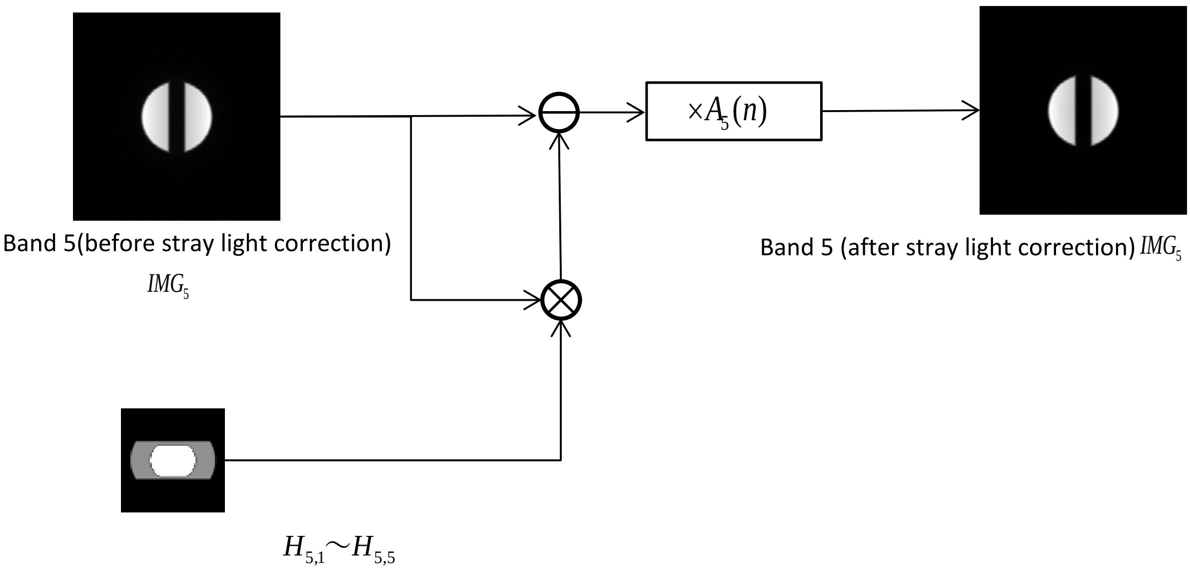

Figure 4-12 Stray light correction (example of band 5)

Because stray light depends on the pixel position in image, we use five $H_{i,a}(u,v)$ from $H_{i,1}(u,v)$ to $H_{i,5}(u,v)$. Figure 4-13 shows example of PSF and applying area.

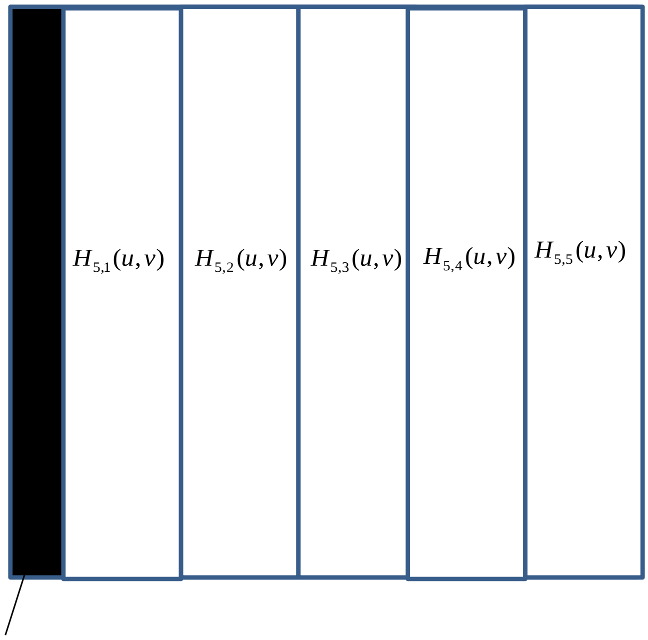

Figure 4-13 PSF and applying area (example of band5)

$H_{i,a}(u,v)$ and the applying area is defined in the parameter file.

PSF applying area is defined within the valid pixel area. We apply the border processing to out of the valid pixel area. The border processing is described in section 4.11.

Before the convolution, the missing line in $IMG_i(n,l)$ must be filled by the interpolation.

The interpolation is described in section 4.10.

$A_i(n)$ is the coefficient in the parameter file.

4.10. Filling missing line by interpolation

As the convolution operation needs to be applied to the spatially continuous image data, the missing lines in the image must be filled by interpolation. The following equation shows the interpolation.

$$IMG_i(n,l) = \frac{IMG_i(n,l_{\max}) - IMG_i(n,l_{\min})}{l_{\max} - l_{\min}}(l - l_{\min}) + IMG_i(n,l_{\min}) \qquad \text{Eq.4.10-1}$$

Where

$IMG_i(n,l)$: The luminance image data of band i(i=1,6) (pixel n, line l : $l_{\min} < l < l_{\max}$)

$l_{\min}, l_{\max}$: The pre/post non-missing line number of the missing line.

Figure 4-14 shows the interpolation of the missing line.

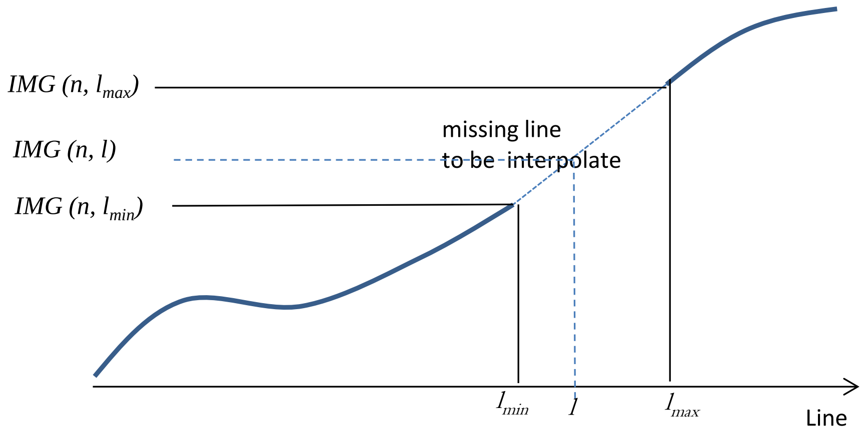

Figure 4-14 Interpolation of the missing line

As the result of band-to-band registration, the first and/or last line of the target image might be missing line. If the first line of the target image is missing line, the lines will be filled with zero between the first line and the first normal line. If the last line of the target image is missing line, the lines will be filled with zero between the last normal line and the last line.

4.11. Image border processing

PSF and its applying area to the image are provided as the parameter file.

The followings are normal range.

Band 1,2,3,4,6,7,8,9 : Pixel 9 to 2056
Band 5, 10 : Pixel 7 to 1024 (include 7 to 66 pixel)

Figure 4-14 shows the PSF applying area.

The pixels out of applying area will be filled with the value of the border area.

For pixel direction, the border filling width is specified by parameter. The parameter specifies the physical width of sensor receiving potentially extra light. The pixels out of the border range are filled with zero. Figure 4-15 shows the image border processing.

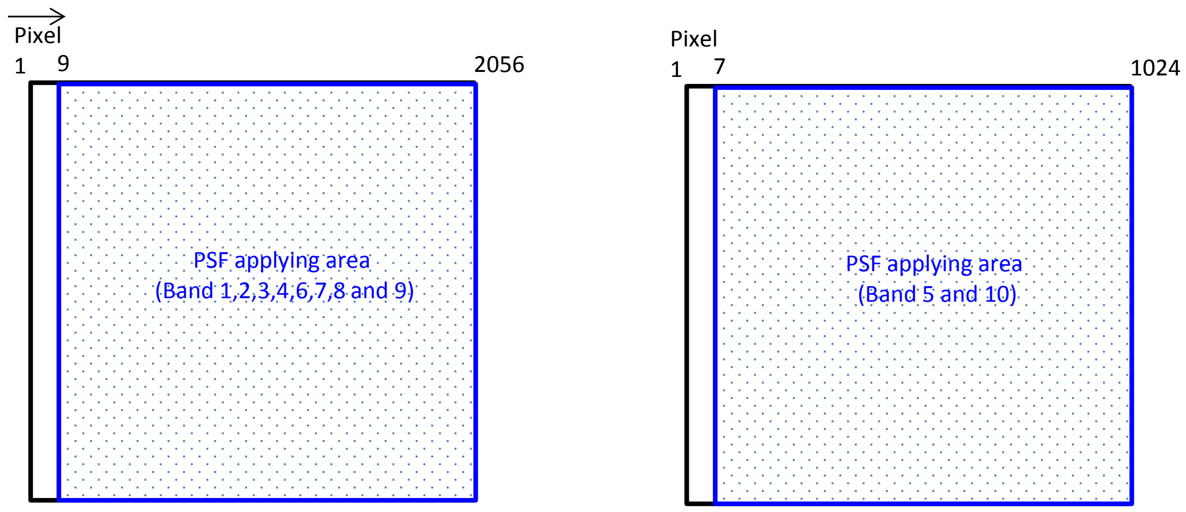

Figure 4-15 PSF applying area

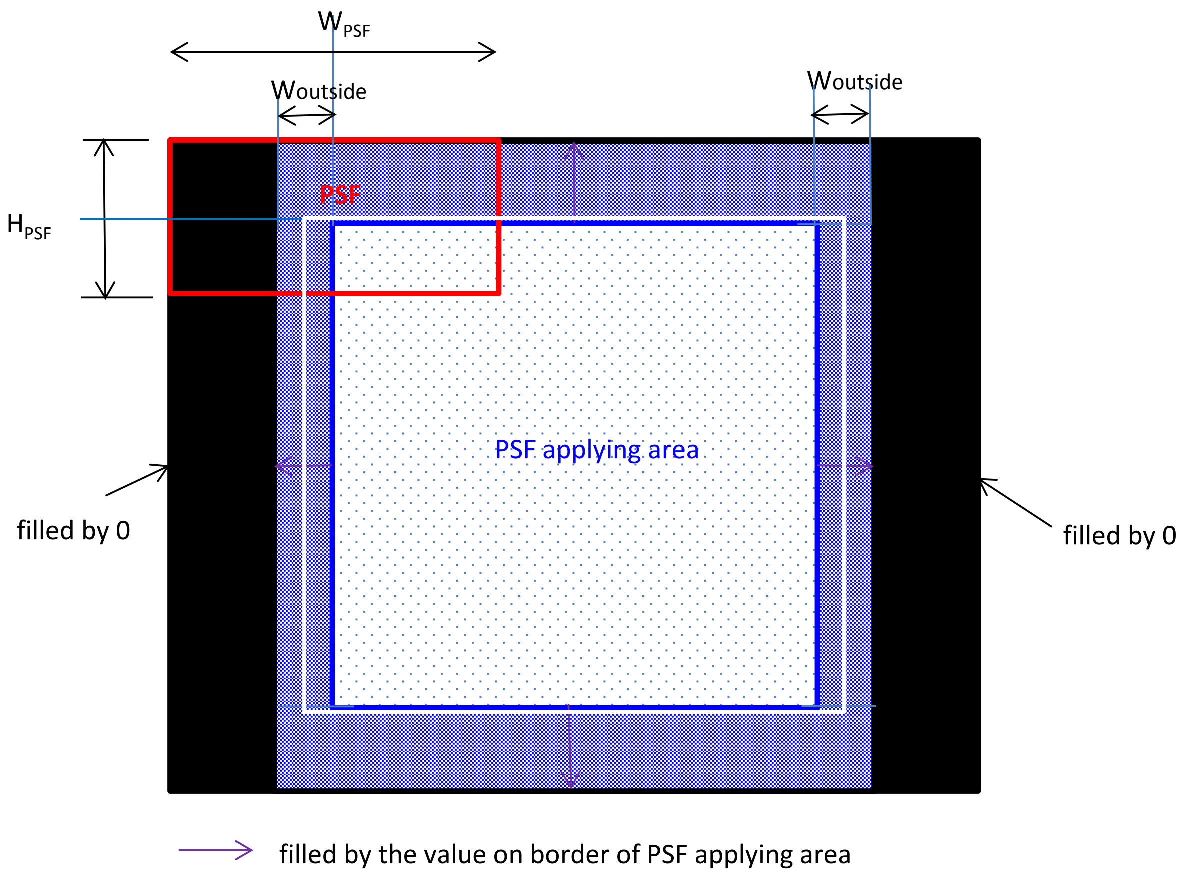

Figure 4-16 Image border processing

White box shows the original image size of target image.

$W_{outside}$ is a parameter. W_{PSF} and H_{PSF} are width/height of PSF.

5. Geometric conversion

Setting of viewing vector, coordinate conversion to ECR coordinate and calculation of observation point are described below.

(1) Definition of view vector in sensor (CAI-2) coordinate

View vector in sensor (CAI-2) coordinate $\mathbf{v}_{\mathbf{sensor}}(m,n)$is calculated below formula as a unit vector for each band *m* and Pixel number *n* .

$$\mathbf{v}_{\mathbf{sensor}}(m,n) = \frac{1}{\sqrt{x^2(m,n)+y^2(m,n)+z^2(m,n)}}\begin{pmatrix} x(m,n) \\ y(m,n) \\ z(m,n) \end{pmatrix}$$

$$x(m,n) = \sum_{j=0}^{10} g_{jx}(m)\cdot p^j(m,n)$$

$$y(m,n) = \sum_{j=0}^{10} g_{jy}(m)\cdot p^j(m,n)$$

$$z(m,n) = \sum_{j=0}^{10} g_{jz}(m)\cdot p^j(m,n)$$

$$p(m,n) = p_{\det}(m)\cdot\left(n - p_c(m)\right)$$

Eq.5-1

Here,

$g_{jk}(m)$ the coefficient of view vector of band *m*, order j. *k* (*k=x,y,z)* means the axis.

$p(m,n)$ the pixel position of pixel *n*, band *m* from the reference position on the detector. (Unit:mm).

$p_{\mathrm{det}}(m)$ the pixel pitch of band *m* of the detector (Unit:mm).

$p_{\mathrm{c}}(m)$ the reference pixel position of band m , on the detector (Unit :pixel)

$g_{jk}(m), p_{\mathrm{det}}(m)$ and $p_{\mathrm{c}}(m)$ are provided in the parameter file.

(2) Conversion from sensor (CAI-2) coordinate to satellite coordinate

Conversion from view vector in sensor (CAI-2) coordinate $\mathbf{v}_{\mathbf{sensor}}$ to view vector in satellite-fixed coordinate $\mathbf{v}_{\mathbf{body}}$ is expressed as follows:

$$\mathbf{v}_{\mathbf{body}} = \mathbf{M}_{\mathbf{sensor-body}} \times \mathbf{v}_{\mathbf{sensor}} \qquad \text{Eq. 5-2}$$

$\mathbf{M}_{\mathbf{sensor\text{-}body}}$ is coordinate transformation matrix convert from sensor (CAI-2) coordinate to satellite coordinate and provided in another file.

(3) Conversion from satellite coordinate to ECR coordinate

Using transformation matrix (satToECR_Matrix) $\mathbf{M}_{\mathbf{body\text{-}ECR}}$ which is stored in SatelliteGeometry group, conversion from view vector in satellite coordinate $\mathbf{v}_{\mathbf{body}}$ to view vector in ECR(WGS84) $\mathbf{v}_{\mathbf{ECR}}$ is expressed as follows:

$$\mathbf{v}_{\mathbf{ECR}} = \mathbf{M}_{\mathbf{body-ECR}} \times \mathbf{v}_{\mathbf{body}} \qquad \text{Eq. 5-3}$$

Conversion from satellite coordinate to J2000.0, TOD, pseudo earth-fixed and ECR coordinate without using $\mathbf{M}_{\mathbf{body\text{-}ECR}}$ is described below.

(4) Conversion from satellite coordinate to J2000.0 coordinate

Conversion from view vector in satellite coordinate $\mathbf{v_{body}}$ to view vector in J2000.0 coordinate $\mathbf{v_{J2000}}$ is expressed as follows:

$$\mathbf{v_{J2000}} = \mathbf{M_{body-J2000}} \times \mathbf{v_{body}} \qquad \text{Eq. 5-4}$$

$\mathbf{M_{body\text{-}J2000}}$ is coordinate transformation matrix converting from satellite coordinate to J2000.0 coordinate using satellite attitude data (quaternion) which is stored in AttitudeData group of Common file (see Chapter 3.4.8).

(5) Conversion from J2000.0 coordinate to TOD coordinate

Using PN matrix which is stored in TransMatrixInfo group of Common file, conversion from view vector in J2000.0 coordinate $\mathbf{v_{J2000}}$ to view vector in TOD coordinate $\mathbf{v_{TOD}}$ is expressed as follows:

$$\mathbf{v_{TOD}} = \mathbf{PN} \times \mathbf{v_{J2000}} \qquad \text{Eq. 5-5}$$

(6) Conversion from TOD coordinate to pseudo earth-fixed coordinate

Conversion from view vector in TOD coordinate $\mathbf{v_{TOD}}$ to view vector in pseudo earth-fixed coordinate (without considering the polar motion) $\mathbf{v_{PECR}}$ is expressed as follows:

$$\mathbf{v_{PECR}} = \mathbf{M_{TOD-PECR}} \times \mathbf{v_{TOD}} \qquad \text{Eq. 5-6}$$

$\mathbf{M_{TOD\text{-}PECR}}$ is coordinate transformation matrix convert from TOD coordinate to pseudo earth-fixed coordinate and calculated using Greenwich sidereal time SiderealTimeInfo group of Common file (see Chapter 3.4.3).

(7) Conversion from pseudo earth-fixed coordinate to ECR coordinate

Using XY matrix is stored in TransMatrixInfo group of Common file, conversion from view vector in pseudo earth-fixed coordinate (without considering polar motion) $\mathbf{v_{PECR}}$ to view vector in ECR $\mathbf{v_{ECR}}$ is expressed as follows:

$$\mathbf{v_{ECR}} = \mathbf{XY} \times \mathbf{v_{PECR}} \qquad \text{Eq. 5-7}$$

(8) Calculation of observation point on the earth ellipsoid

Using view vector in ECR coordinate $\mathbf{v_{ECR}}=(v_x, v_y, v_z,)^t$ (the superscript t denotes transpose), sensor position vector $\mathbf{p_{sat}}=(p_{sat\_x}, p_{sat\_y}, p_{sat\_z})^t$ and observation point vector on the earth ellipsoid $\mathbf{p_{obs}}=(p_{obs\_x}, p_{obs\_y}, p_{obs\_z})^t$, observation point is expressed as follows:

$$\begin{pmatrix} p_{obs\_x} \\ p_{obs\_y} \\ p_{obs\_z} \end{pmatrix} = \begin{pmatrix} p_{sat\_x} \\ p_{sat\_y} \\ p_{sat\_z} \end{pmatrix} + k \begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} \qquad \text{Eq. 5-8}$$

k is intermediate variable.

When the equatorial radius and polar radius on the earth ellipsoid is *Re* and *Rp*, $\mathbf{p_{obs}}=(p_{obs\_x}, p_{obs\_y}, p_{obs\_z})^t$ satisfies the following relational expression :

$$\frac{p_{obs\_x}^2 + p_{obs\_y}^2}{R_e^2} + \frac{p_{obs\_z}^2}{R_p^2} = 1 \qquad \text{Eq. 5-9}$$

Assigning Eq.5-7 to Eq.5-8, quadratic equation for *k* is obtained as follows:

$$ak^2 + 2bk + c = 0$$
$$\text{where} \qquad \text{Eq. 5-10}$$
$$\begin{cases} a = R_p^2\left(v_x^2 + v_y^2\right) + R_e^2 v_z^2 \\ b = R_p^2\left(p_{sat\_x}v_x + p_{sat\_y}v_y\right) + R_e^2 p_{sat\_z}v_z \\ c = R_p^2\left(p_{sat\_x}^2 + p_{sat\_y}^2\right) + R_e^2 p_{sat\_z}^2 - R_e^2 R_p^2 \end{cases}$$

Then, Eq. 5-9 is solved for *k*.

$$k = \frac{-b - \sqrt{b^2 - ac}}{a} \qquad \text{Eq. 5-11}$$

In case b^2-$ac < 0$ and $k < 0$, observation point is outside of earth surface.

Assigning k to Eq.5-7, observation point vector $\mathbf{p_{obs}}=(p_{obs\_x}, p_{obs\_y}, p_{obs\_z})^t$ can be calculated.

Figure 5-1 shows each vector.

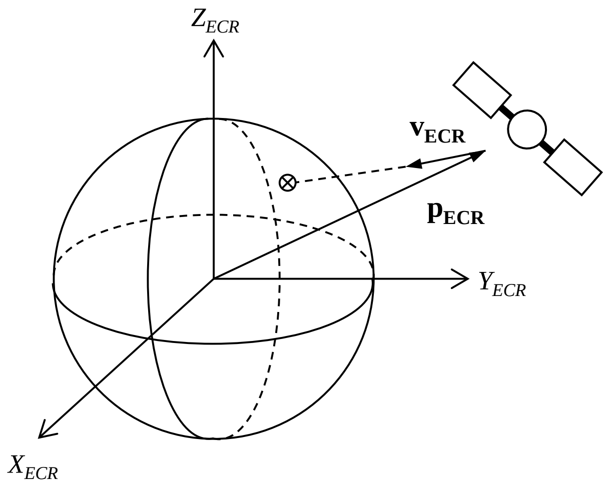

Figure 5-1 Calculation of observation point

(9) Calculation of geographic latitude/longitude

Geographic longitude λ corresponding observation point vector of the earth ellipsoid $\mathbf{p_{obs}}=(p_{obs\_x}, p_{obs\_y}, p_{obs\_z})^t$ is expressed as follows:

$$\lambda = \mathrm{atan}\,2(p_{obs\_y}, p_{obs\_x}) \tag{Eq. 5-12}$$

Using geocentric latitude ψ, geographic latitude φ can be calculated as follows:

$$\psi = \mathrm{asin}\left(\frac{p_{obs\_z}}{\sqrt{p_{obs\_x}^2 + p_{obs\_y}^2 + p_{obs\_z}^2}} \right) \tag{Eq. 5-13}$$

$$\varphi = \mathrm{atan}\,2\left(\sin\psi,\ \frac{R_p^2}{R_e^2}\cos\psi \right) \tag{Eq. 5-14}$$

Definition of atan2 function is described below.

$$\mathrm{atan}\,2(y, x) = \begin{cases} \tan^{-1}\left(\frac{y}{x}\right) & (x > 0) \\ \tan^{-1}\left(\frac{y}{x}\right) + \pi & (x < 0, y \geq 0) \\ \tan^{-1}\left(\frac{y}{x}\right) - \pi & (x < 0, y < 0) \\ \frac{\pi}{2} & (x = 0, y > 0) \\ -\frac{\pi}{2} & (x = 0, y < 0) \\ undefined & x = 0, y = 0 \end{cases} \tag{Eq. 5-15}$$

6. Format Details

The details of product (HDF5) and L1 processing result file (XML) format are described below.

Table 6-1 shows the format details of Common file (HDF5) and Table 6-2 shows the format details of Forward/Backward looking band file (L1A/ HDF5).

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (1/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
Metadata									
granuleID	1	1	H5T_STRING	File Identifier (Granule ID)	Granule ID (47bytes, the last 1 byte is a null terminated string) ・ Satellite Name：GOSAT2 (Fixed) ・ Sensor Name：TANSO-CAI2：TCAI2 (Fixed) ・ Start Time of Observation (year・month・day・hour・minute) : YYYYMMDDHHmm (UTC) ・ Path No. : PPP(001-089) ・ Scene No. : 00(Fixed) ・ Processing Level：1A(Fixed) ・ Band：C(Fixed) ・ Orbit data used for processing：R Using predicted orbit data：P Using GPS or determined orbit data：D ・ Correction coefficients used for processing：C Using nominal coefficients：N Using updated coefficients：U ・ Reserved：00 ・ Operation Mode：OOOO Observation Mode (day) : OBSM Dark calibration mode：NCAL Electric calibration mode：ECAL Lunar calibration mode：LCAL ・ Algorithm Version：AAA(000-999) ・ Parameter Version：BBB(000-999)	-	-	-	Start Time of observation (UTC) is the oldest time of the first line observed by FWD looking band or BWD looking band. Normally the time will be the same as observation time at the first line of FWD looking band because observation is started with FWD looking band. The observation time here is the integration start time and common to all bands, because the integration time depends on bands.
operationMode	1	1	H5T_STRING	Sensor Operation Mode	"OBSM"：Observation Mode (day) "NCAL"：Dark calibration mode "ECAL"：Electric calibration mode "LCAL"：Lunar calibration mode (5bytes, the last 1 byte is a null terminated string)	-	-	-	
processingDate	1	1	H5T_STRING	Processing date	Date of product creation (UTC) Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	Time when creation job started is stored.
startDateFwd	1	1	H5T_STRING	Start date of scene of Forward looking band	Start date of scene of Forward looking band(UTC) Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string) If there is no forward looking data in this scene, "-"(2bytes, the last 1 byte is a null terminated string) is stored.	UTC	-	"-"	The oldest observation time of forward looking without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (2/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
endDateFwd	1	1	H5T_STRING	End date of scene of Forward looking band	End date of scene of Forward looking band(UTC) Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string) If there is no forward looking data in this scene, ″-″(2bytes, the last 1 byte is a null terminated string) is stored.	UTC	-	″-″	The latest observation time of forward looking without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.
startDateBwd	1	1	H5T_STRING	Start date of scene of Backward looking band	Start date of scene of Backward looking band(UTC) Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string) If there is no backward looking data in this scene, ″-″(2bytes, the last 1 byte is a null terminated string) is stored.	UTC	-	″-″	The oldest observation time of backward looking without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.
endDateBwd	1	1	H5T_STRING	End date of scene of Backward looking band	End date of scene of Backward looking band(UTC) Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string) If there is no backward looking data in this scene, ″-″(2bytes, the last 1 byte is a null terminated stringe) is stored.	UTC	-	″-″	The latest observation time of backward looking without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.
geodeticDatum	1	1	H5T_STRING	Geodetic datum	″WGS84/ WGS84″:Reference Ellipsoid Model/Frame of Reference Fixed (14bytes, the last 1 byte is a null terminated string)	-	-	-	
satelliteName	1	1	H5T_STRING	Satellite Name	″GOSAT-2″： Greenhouse gases Observing SATellite-2 Fixed (8bytes, the last 1 byte is a null terminated string)	-	-	-	
sensorName	1	1	H5T_STRING	Sensor Name	″TANSO-CAI-2″： Cloud and Aerosol Imager-2 Fixed (12bytes, the last 1 byte is a null terminated string)	-	-	-	
processingLevel	1	1	H5T_STRING	Processing Level	″L1A″：Level 1A (4bytes, the last 1 byte is a null terminated string)	-	-	-	
algorithmVersion	1	1	H5T_STRING	Algorithm Version	Algorithm vertsion in processing control information is stored. (4bytes, the last 1 byte is a null terminated string)	-	-	-	
parameterVersion	1	1	H5T_STRING	ParameterVersion	Parameter vertsion in processing control information is stored. (4bytes, the last 1 byte is a null terminated string)	-	-	-	
processingFacility	1	1	H5T_STRING	Processing facility name	″G2MDP″：Mission Operations System Data Processing ″JSS″：JAXA Super computer System ″EORC″：Earth Observation Research Center (the size is the length of string above plus 1byte)	-	-	-	

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (3/12)

Group Path/Dataset Name	Data size: Dimension	Data size: Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
contact_01	1	1	H5T_STRING	Organization Name1	"Japan Aerospace Exploration Agency (JAXA)" Fixed (42bytes, the last 1 byte is a null terminated string)	–	–	–	
contact_02	1	1	H5T_STRING	Organization Name2	"National Institute for Environmental Studies (NIES)" Fixed (52bytes, the last 1 byte is a null terminated string)	–	–	–	
email	1	1	H5T_STRING	e-mail address	e-mail address Fixed (Variable size. (the size is the length of string above plus 1byte)	–	–	–	
releaseVersion	1	1	H5T_STRING	Release version	Release version is stored (Variable size. (the size is the length of string above plus 1byte)	–	–	–	
granuleIDFwd	1	1	H5T_STRING	Granule ID of FWD looking band file	Granule ID of Forward looking band file is stored. (47 bytes, the last 1 byte is a null terminated string) If there is no forward looking data, the granuleID is empty string. (The string terminator 1byte only)	–	–	""	–
granuleIDBwd	1	1	H5T_STRING	Granule ID of BWD looking band file	Granule ID of BWD looking band file is stored. (47 bytes, the last 1 byte is a null terminated string) If there is no backward looking data, the granuleID is empty string. (The string terminator 1byte only)	–	–	""	–
productQualityFlag	1	1	H5T_STRING	Product quality flag	Quality of product on a four level scale as follows: "Good", "Fair", "Poor", "NG" (the size is the length of string above plus 1byte)	–	–	–	When productQualityFlag is "NG", product isn't provided to user.
SpacecraftTimeError (Spacecraft time error information)									
numDiffInfo	1	1	H5T_STD_I32LE	Number of Time Difference Information Records	Number of Time Difference Information Records. (When Time System is GPS, 0 is set.) The items in this group are used when two time systems between the interior time system of satellite and that of the ground station are interchanged. *ground time = (ground reference time) + (satellite counter period) * (satellite counter) *satellite counter = (ground time) - (ground reference time in second) + (satellite time reference counter)	–	–	0	

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (4/12)

Group Path/Dataset Name	Data size: Dimension	Data size: Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
startDate	1	numDiffInfo	H5T_STRING	Start date	The start time at the first record of Time Difference information Record in this path. There is no dataset if numDiffInfo is 0. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string x numDiffInfo)	UTC	-	-	There is no dataset if numDiffInfo is 0.
endDate	1	numDiffInfo	H5T_STRING	End date	The end time at the last record of Time Difference information Record in this path. There is no dataset if numDiffInfo is 0. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string x numDiffInfo)	UTC	-	-	There is no dataset if numDiffInfo is 0.
groundTime	1	numDiffInfo	H5T_STRING	Ground Reference Time	Ground Reference Time. There is no dataset if numDiffInfo is 0. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string x numDiffInfo)	UTC	-	-	There is no dataset if numDiffInfo is 0.
refCount	1	numDiffInfo	H5T_STD_I32LE	Satellite Reference Time	Satellite Reference Time. There is no dataset if numDiffInfo is 0.	sec	-	-	There is no dataset if numDiffInfo is 0.
periodCount	1	numDiffInfo	H5T_IEEE_F64LE	Satellite Counter Period	Satellite Counter Period. Time duration corresponding to 1 count during the valid data range. There is no dataset if numDiffInfo is 0.	sec	10	-	There is no dataset if numDiffInfo is 0.
SiderealTimeInfo									
numData	1	1	H5T_STD_I32LE	Number of Greenwich sidereal time parameters	Number of parameters to calculate Greenwich sidereal time is stored.	-	-	0	
t0	1	numData	H5T_STRING	t0(UTC)	Reference time t0 is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string) Using t0, θg, and θg_dot, Greenwich sidereal time θg is expressed as follows: θg = θg0 + θg_dot * (t - t0)	UTC	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (5/12)

Group Path/Dataset Name	Data size: Dimension	Data size: Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
t0_ContinuousTime	1	numData	H5T_IEEE_F64LE	t0 (seconds)	Total seconds since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
thetaG0	1	numData	H5T_IEEE_F64LE	θg0	Greenwich sidereal angle at the reference time θg0. 0≦ θg0 < 360	deg	10	-	There is no dataset if numData is 0.
thetaGDot	1	numData	H5T_IEEE_F64LE	θg_dot	Time derivative of Greenwich sidereal angle ~~time~~ θg_dot is stored.	deg/sec	10	-	There is no dataset if numData is 0.
TransMatrixInfo									
numMatrix	1	1	H5T_STD_I32LE	Number of Coordinate Transformation	Number of coordinate transformation matrix.	-	-	0	
date	1	numMatrix	H5T_STRING	Date corresponding PN and XY matrix(UTC)	Date and time at PN and XY matrix (UTC). Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28 bytes, the last 1 byte is a null terminated stringxnumMatrix)	UTC	-	-	There is no dataset if numMatrix is 0.
date_ContinuousTime	1	numMatrix	H5T_IEEE_F64LE	Date corresponding PN and XY matrix(seconds)	Total seconds at PN, XY since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numMatrix is 0.
pnMatrix	2	numMatrix,9	H5T_IEEE_F64LE	PN Matrix	The values of matrix PN are stored in the following order: (0, 1, 2) (3, 4, 5) (6, 7, 8). PN is the conversion matrix expression polar precess and nutation of earth and is used to convert ECI(J2000) coordinate to ECI(TOD).	-	10	-	There is no dataset if numMatrix is 0.
xyMatrix	2	numMatrix,9	H5T_IEEE_F64LE	XY Matrix	The values of matrix XY are stored in the following order: (0, 1, 2) (3, 4, 5) (6, 7, 8). XY matrix is the conversion matrix from pseudo earth-fixed coordinates without considering polar motion of earth to ECR(WGS84) coordinate.	-	10	-	There is no dataset if numMatrix is 0.
OnboardOrbitData									
numData	1	1	H5T_STD_I32LE	Number of onboard orbit data	Number of onboard orbit data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of onboard orbit data (UTC)	Start date of onboard orbit data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of onboard orbit data (seconds)	Total seconds of start date of onboard orbit data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (6/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of onboard orbit data	The elapsed seconds from start date of onboard orbit data.	sec	10	-	There is no dataset if numData is 0.
posECR	2	numData,3	H5T_IEEE_F64LE	Satellite Position Vector(ECR)	Satellite Position Vector in ECR is stored. (x,y,z) ECR(WGS84)	km	10	-	There is no dataset if numData is 0.
velECR	2	numData,3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECR)	Satellite Velocity Vector in ECR is stored. (u,v,w) ECR(WGS84)	km/s	10	-	There is no dataset if numData is 0.
posECI	2	numData,3	H5T_IEEE_F64LE	Satellite Position Vector(ECI)	Satellite Position Vector in ECI is stored. (x,y,z) ECI(TOD)	km	10	-	There is no dataset if numData is 0.
velECI	2	numData,3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECI)	Satellite Velocity Vector in ECI is stored. (u,v,w) ECI(TOD)	km/s	10	-	There is no dataset if numData is 0.
KinematicOrbitDataPredicted (From_ Knematic orbit data_system in JAXA)									
numData	1	1	H5T_STD_I32LE	Number of predicted kinematic orbit data	Number of predicted kinematic orbit data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of predicted kinematic orbit data (UTC)	Start date of predicted kinematic orbit data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of predicted kinematic orbit data (seconds)	Total seconds of reference time of predicted kinematic orbit data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of predicted kinematic orbit data	The elapsed seconds from start date of predicted kinematic orbit data.	sec	10	-	There is no dataset if numData is 0.
posECR	2	numData,3	H5T_IEEE_F64LE	Satellite Position Vector(ECR)	Satellite Position Vector in ECR is stored. (x,y,z) ECR(WGS84)	km	10	-	There is no dataset if numData is 0.
velECR	2	numData,3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECR)	Satellite Velocity Vector in ECR is stored. (u,v,w) ECR(WGS84)	km/s	10	-	There is no dataset if numData is 0.
posECI	2	numData,3	H5T_IEEE_F64LE	Satellite Position Vector(ECI)	Satellite Position Vector in ECI is stored. (x,y,z) ECI(TOD)	km	10	-	There is no dataset if numData is 0.
velECI	2	numData,3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECI)	Satellite Velocity Vector in ECI is stored. (u,v,w) ECI(TOD)	km/s	10	-	There is no dataset if numData is 0.
KinematicOrbitDataDetermined (From Kinematic orbit data system in JAXA)									
numData	1	1	H5T_STD_I32LE	Number of determined kinematic orbit	Number of determined kinematic orbit data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of determined kinematic orbit data (UTC)	Start date of determined kinematic orbit data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (7/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of Determined kinematic orbit data(seconds)	Total seconds of start date of determined kinematice orbit data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of determined kinematic orbit data	The elapsed seconds from start date of determined kinematic orbit data.	sec	10	-	There is no dataset if numData is 0.
posECR	2	numData, 3	H5T_IEEE_F64LE	Satellite Position Vector(ECR)	Satellite Position Vector in ECR is stored. (x, y, z) ECR(WGS84)	km	10	-	There is no dataset if numData is 0.
velECR	2	numData, 3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECR)	Satellite Velocity Vector in ECR is stored. (u, v, w) ECR(WGS84)	km/s	10	-	There is no dataset if numData is 0.
posECI	2	numData, 3	H5T_IEEE_F64LE	Satellite Position Vector(ECI)	Satellite Position Vector in ECI is stored. (x, y, z) ECI(TOD)	km	10	-	There is no dataset if numData is 0.
velECI	2	numData, 3	H5T_IEEE_F64LE	Satellite Velocity Vector(ECI)	Satellite Velocity Vector in ECI is stored. (u, v, w) ECI(TOD)	km/s	10	-	There is no dataset if numData is 0.
AttitudeData									
numData	1	1	H5T_STD_I32LE	Number of attitude data	Number of attitude data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of attitude data (UTC)	Start date of attitude data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of attitude data (seconds)	Total seconds of reference time of attitude data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of attitude data	The elapsed seconds from start date of attitude data.	sec	10	-	There is no dataset if numData is 0.
satAttQuaternion	2	numData, 4	H5T_IEEE_F64LE	Satellite Attitude Quaternion	Quaternion (satellite-fixed coordinates at ECI(J2000)) is stored. q0 is scalar data. q1,q2 and q3 are i, j, and k respectively.	-	10	-	There is no dataset if numData is 0.
yawSteeringFlag	1	numData	H5T_STD_I8LE	Yaw steering flag	Yaw steering flag indicates the executing condition of yaw steering. 0: Not execute 1: Execute	-	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (8/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
SolarEphemeris									
numData	1	1	H5T_STD_I32LE	Number of data	Number of solar ephemeris data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of solar ephemeris data (UTC)	Start date of solar ephemeris data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of solar ephemeris data (seconds)	Total seconds of start date of solar ephemeris data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from Start time start date of solar ephemeris data	The elapsed seconds from start date of solar ephemeris data.	sec	10	-	There is no dataset if numData is 0.
posECR	2	numData,3	H5T_IEEE_F64LE	Solar Position Vector(ECR)	Solar Position Vector in ECR is stored. (x,y,z) ECR(WGS84)	km	10	-	There is no dataset if numData is 0.
velECR	2	numData,3	H5T_IEEE_F64LE	Solar Velocity Vector(ECR)	Solar Velocity Vector in ECR is stored. (u,v,w) ECR(WGS84)	km/s	10	-	There is no dataset if numData is 0.
posECI	2	numData,3	H5T_IEEE_F64LE	Solar Position Vector(ECI)	Solar Position Vector in ECI is stored. (x,y,z) ECI(TOD)	km	10	-	There is no dataset if numData is 0.
velECI	2	numData,3	H5T_IEEE_F64LE	Solar Velocity Vector(ECI)	Solar Velocity Vector in ECI is stored. (u,v,w) ECI(TOD)	km/s	10	-	There is no dataset if numData is 0.
LunarEphemeris									
numData	1	1	H5T_STD_I32LE	Number of data	Number of lunar ephemeris data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of lunar ephemeris data (UTC)	Start date of lunar ephemeris data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of lunar ephemeris data (seconds)	Total seconds of start date of lunar ephemeris data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of lunar ephemeris data	The elapsed seconds from start date of lunar ephemeris data.	sec	10	-	There is no dataset if numData is 0.
posECR	2	numData,3	H5T_IEEE_F64LE	Lunar Position Vector(ECR)	Lunar Position Vector in ECR is stored. (x,y,z) ECR(WGS84)	km	10	-	There is no dataset if numData is 0.
velECR	2	numData,3	H5T_IEEE_F64LE	Lunar Velocity Vector(ECR)	Lunar Velocity Vector in ECR is stored. (u,v,w) ECR(WGS84)	km/s	10	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (9/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
posECI	2	numData,3	H5T_IEEE_F64LE	Lunar Position Vector(ECI)	Lunar Position Vector in ECI is stored. (x,y,z) ECI(TOD)	km	10	–	There is no dataset if numData is 0.
velECI	2	numData,3	H5T_IEEE_F64LE	Lunar Velocity Vector(ECI)	Lunar Velocity Vector in ECI is stored. (u,v,w) ECI(TOD)	km/s	10	–	There is no dataset if numData is 0.
TemperatureTelemetry_1sec (Temperature telemetry of 1 sec period)									
numData	1	1	H5T_STD_I32LE	Number of data	Number of data is stored.	–	–	0	
startDate	1	1	H5T_STRING	Start date of data (UTC)	Start date of data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	–	–	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of data (seconds)	Total seconds of start date of data since 23:59:59 UTC, Dec 31, 2012.	sec	–	–	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of data	The elapsed seconds from start date of data.	sec	10	–	There is no dataset if numData is 0.
sensorTemp	2	numData,10	H5T_IEEE_F64LE	Sensor temperature	Sensor temperature is stored for each band.	℃	10	–	There is no dataset if numData is 0.
sensorTempQuality	2	numData,10	H5T_STD_I8LE	Quality flag of sensor temperature	Quality flag of sensor temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	–	–	–	There is no dataset if numData is 0.
preAmpTemp	2	numData,10	H5T_IEEE_F64LE	Pre-amplifier temperature	Pre-amplifier temperature is stored for each band.	℃	10	–	There is no dataset if numData is 0.
preAmpTempQuality	2	numData,10	H5T_STD_I8LE	Quality flag of Pre-amplifier temperature	Quality flag of Pre-amplifier temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	–	–	–	There is no dataset if numData is 0.
AmpTemp	2	numData,10	H5T_IEEE_F64LE	Amplifier temperature	Amplifier temperature is stored for each band.	℃	10	–	There is no dataset if numData is 0.
AmpTempQuality	2	numData,10	H5T_STD_I8LE	Quality flag of Amplifier temperature	Quality flag of Amplifier temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	–	–	–	There is no dataset if numData is 0.
lensM_Temp	2	numData,5	H5T_IEEE_F64LE	lens(M) temperature	Lens(M) temperature is stored for each lens.	℃	10	–	There is no dataset if numData is 0.
lensM_TempQuality	2	numData,5	H5T_STD_I8LE	Quality flag of lens(M) temperature	Quality flag of lens(M) temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	–	–	–	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (10/12)

Group Path/Dataset Name	Data size: Dimension	Data size: Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
TemperatureTelemetry_32sec (Temperature telemetry of 32 sec period)									
numData	1	1	H5T_STD_I32LE	Number of data	Number of data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of data (UTC)	Start date of data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of data (seconds)	Total seconds of start date of data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of data	The elapsed seconds from start date of data.	sec	10	-	There is no dataset if numData is 0.
postAmpTemp	2	numData, 10	H5T_IEEE_F64LE	Post amplifier temperature	Post amplifier temperature is stored for each band.	℃	10	-	There is no dataset if numData is 0.
postAmpTempQuality	2	numData, 10	H5T_STD_I8LE	Quality flag of Post amplifier temperature	Quality flag of Post amplifier temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	-	-	-	There is no dataset if numData is 0.
lensT_Temp	2	numData, 5	H5T_IEEE_F64LE	Lens(T) temperature	Lens(T) temperature is stored for each lens.	℃	10	-	There is no dataset if numData is 0.
lensT_TempQuality	2	numData, 5	H5T_STD_I8LE	Quality flag of Lens(T) temperature	Quality flag of Lens(T) temperature is stored. 0：Normal 1：Abnormal (outside the acceptable range) 2: Quality is unknown due to data loss and so on	-	-	-	There is no dataset if numData is 0.
HK_Telemetry_1sec (Telemetry of 1 sec period except for temperature telemetry)									
numData	1	1	H5T_STD_I32LE	Number of data	Number of data is stored.	-	-	0	
startDate	1	1	H5T_STRING	Start date of data (UTC)	Start date of data (UTC) is stored. Time format：YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	There is no dataset if numData is 0.
startDate_ContinuousTime	1	1	H5T_IEEE_F64LE	Start date of data (seconds)	Total seconds of start date of data since 23:59:59 UTC, Dec 31, 2012.	sec	-	-	There is no dataset if numData is 0.
time	1	numData	H5T_IEEE_F64LE	Elapse time from start date of data	The elapsed seconds from start date of data.	sec	10	-	There is no dataset if numData is 0.
gainSetting_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of Gain	Enable/Disable setting of Gain is stored. 0: Disable 1: Enable	-	-	-	There is no dataset if numData is 0.
sensorGain	2	numData, 5	H5T_STD_I8LE	Sensor gain	Sensor gain is stored for each lens.	-	-	-	There is no dataset if numData is 0.
OC_OCMODE_STS	1	numData	H5T_STD_I8LE	OC_OCMODE_STS	OC_OCMODE_STS is stored. 0: OFF 1: Standby 2: Oparating	-	-	-	There is no dataset if numData is 0.
OC_EE_DIAG_RESULT	1	numData	H5T_STD_I8LE	OC_EE_DIAG_RESULT	OC_EE_DIAG_RESULT is stored. 0: OK 1: Error	-	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (11/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
OC_FW_STS_MODE	1	numData	H5T_STD_I8LE	OC_FW_STS_MODE	OC_FW_STS_MODE is stored. 0: READY 1: COPY 2: CHECK 3: REMASTER 4: VERIFY 5: - 6: - 7: ACCERR 8: CORRECT 9: REBUILD 10: ROMCARE	-	-	-	There is no dataset if numData is 0.
PWR_Setting	2	numData,6	H5T_STD_I8LE	Power ON/OFF	Power ON/OFF is stored in order of lens1, lens2, lens3, lens4, lens5A, lens5B. 0: OFF 1: ON	-	-	-	There is no dataset if numData is 0.
DSP_A	1	numData	H5T_STD_I8LE	DPS(A)ON/OFF	DPS(A)ON/OFF is stored. 0: OFF 1: ON	-	-	-	There is no dataset if numData is 0.
DSP_B	1	numData	H5T_STD_I8LE	DPS(B)ON/OFF	DPS(B)ON/OFF is stored. 0: OFF 1: ON	-	-	-	There is no dataset if numData is 0.
OC_REF_VOLTAGE	1	numData	H5T_STD_U8LE	OC_REF_VOLTAGE	OC_REF_VOLTAGE is stored.	-	-	-	There is no dataset if numData is 0.
IMG_CYCLE_SET_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of IMG_CYCLE	Enable/Disable setting of IMG_CYCLE is stored. 0: disable 1: enable	-	-	-	There is no dataset if numData is 0.
IMG_CYCLE_B1_4_B6_9	1	numData	H5T_STD_U8LE	IMG_CYCLE_B1-4_B6-9	IMG_CYCLE_B1-4_B6-9 is stored.	-	-	-	There is no dataset if numData is 0.
IMG_CYCLE_B5_B10	1	numData	H5T_STD_U8LE	IMG_CYCLE_B5_B10	IMG_CYCLE_B5_B10 is stored.	-	-	-	There is no dataset if numData is 0.
DSP_ASP_CTL_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of DSP-ASP_CTL	Enable/Disable setting of DSP-ASP_CTL is stored. 0: disable 1: enable	-	-	-	There is no dataset if numData is 0.
DSP-ASP_CTL	2	numData,5	H5T_STD_I8LE	DSP-ASP_CTL	DSP-ASP_CTLis stored for each lens.	-	-	-	There is no dataset if numData is 0.
CAL_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of CAL	Enable/Disable setting of CAL is stored. 0: disable 1: enable	-	-	-	There is no dataset if numData is 0.
CAL_ELEC	1	numData	H5T_STD_I8LE	Electrical calibration mode ON/OFF	Electrical calibration mode ON/OFF is stored. 0: OFF 1: ON	-	-	-	There is no dataset if numData is 0.
CAL_NIGHT	1	numData	H5T_STD_I8LE	Dark calibration mode ON/OFF	Dark calibration mode ON/OFF is stored. 0: OFF 1: ON	-	-	-	There is no dataset if numData is 0.

Table 6-1 Dataset definition of CAI-2 L1A common file (HDF5) (12/12)

Group Path/Dataset Name	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
	Dimension	Size							
CAL_LUNA	1	numData	H5T_STD_I8LE	Lunar Calibration mode ON/OFF	Lunar calibration mode ON/OFF is stored. 0: OFF 1: ON	–	–	–	There is no dataset if numData is 0.
DSP_MDP_CTL_F_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of DSP_MDP_CTL_F	Enable/Disable setting of DSP_MDP_CTL_F is stored. 0: disable 1: enable	–	–	–	There is no dataset if numData is 0.
DSP_MDP_CTL_B_E_D	1	numData	H5T_STD_I8LE	Enable/Disable setting of DSP_MDP_CTL_B	Enable/Disable setting of DSP_MDP_CTL_B is stored. 0: disable 1: enable	–	–	–	There is no dataset if numData is 0.
DSP_MDP_CTL	2	numData,10	H5T_STD_I8LE	DSP_MDP_CTL	DSP_MDP_CTLis stored for each band.	–	–	–	There is no dataset if numData is 0.
INTEG_COUNT_E_D	2	numData,10	H5T_STD_I8LE	Enable/Disable setting of INTEG_COUNT	Enable/Disable setting of INTEG_COUNT is stored. 0: disable 1: enable	–	–	–	There is no dataset if numData is 0.
INTEG_COUNT	2	numData,10	H5T_STD_U8LE	INTEG_COUNT	INTEG_COUNTis stored each band.	–	–	–	There is no dataset if numData is 0.

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (1/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
			Dimension	Size							
Metadata											
granuleID	Forward, Backward	OBS, CAL	1	1	H5T_STRING	File Identifier (Granule ID)	Granule ID (47bytes, the last 1 byte is a null terminated string) ・ Satellite Name : GOSAT2 (Fixed) ・ Sensor Name : TANSO-CAI2 : TCAI2 (Fixed) ・ Start Time of Observation (year・month・day・hour・minute) : YYYYMMDDHHmm (UTC) ・ Path No. : PPP(001-089) ・ Scene No. : 00(Fixed) ・ Processing Level : 1A(Fixed) ・ Band : Forward looking band(Band1-5) : F Backward looking band(Band6-10) : B ・ Orbit data used for processing : R Using predicted orbit data : P Using GPS or determined orbit data : D ・ Correction coefficients used for processing: Using nominal coefficients : N Using updated coefficients : U ・ Reserved : 00 ・ Operation Mode : 0000 Observation Mode (day) : OBSM Dark calibration mode : NCAL Electric calibration mode : ECAL Lunar calibration mode : LCAL ・ Algorithm Version : AAA(000-999) ・ Parameter Version : BBB(000-999)	-	-	-	Start Time of observation (UTC) is the oldest time of the first line observed by FWD looking band or BWD looking band. Normally the time will be the same as observation time at the first line of FWD looking band because observation is started with FWD looking band. The observation time here is the integration start time and common to all bands, because the integration time depends on bands.
operationMode	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Sensor Operation Mode	"OBSM" : Observation Mode (day) "NCAL" : Dark calibration mode "ECAL" : Electric calibration mode "LCAL" : Lunar calibration mode (5bytes, the last 1 byte is a null terminated string)	-	-	-	
processingDate	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Processing date	Date of product creation (UTC) Time format : YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	Time when creation job started is stored.
startDate	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Start date of CAI-2 data	Start date of CAI-2 data (UTC) Time format : YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	The oldest observation time without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.
endDate	Forward, Backward	OBS, CAL	1	1	H5T_STRING	End date of CAI-2 data	End date of CAI-2 data(UTC) Time format : YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string)	UTC	-	-	The latest observation time without integration time is stored. The time here is the integration start time and common to all bands, because the integration time depends on bands.
geodeticDatum	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Geodetic datum	"WGS84/ WGS84":Reference Ellipsoid Model/Frame of Reference Fixed (14bytes, the last 1 byte is a null terminated string)	-	-	-	
satelliteName	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Satellite Name	"GOSAT-2": Greenhouse gases Observing SATellite-2 Fixed (8bytes, the last 1 byte is a null terminated string)	-	-	-	
sensorName	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Sensor Name	"TANSO-CAI-2": Cloud and Aerosol Imager-2 Fixed (12bytes, the last 1 byte is a null terminated string)	-	-	-	
processingLevel	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Processing Level	"L1A" : Level 1A (4bytes, the last 1 byte is a null terminated string)	-	-	-	
algorithmVersion	Forward, Backward	OBS, CAL	1	1	H5T_STRING	Algorithm Version	Algorithm vertsion is stored in processing control information (4bytes, the last 1 byte is a null terminated string)	-	-	-	
parameterVersion	Forward, Backward	OBS, CAL	1	1	H5T_STRING	ParameterVersion	Parameter vertsion is stored in processing control information (4bytes, the last 1 byte is a null terminated string)	-	-	-	

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (2/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
			Dimension	Size							
granuleIDCommon	Forward,Backward	OBS,CAL	1	1	H5T_STRING	Granule ID of common file	Granule ID of common file is stored (47bytes, the last 1 byte is a null terminated string)	－	－	－	
processingFacility	Forward,Backward	OBS,CAL	1	1	H5T_STRING	Processing facility name	"G2MDP"：Mission Operations System Data Processing "JSS"：JAXA Super computer System "EORC"：Earth Observation Research Center (the size is the length of string above plus 1byte)	－	－	－	
ScanAttribute(Synchronize with observation point)											
bands_500	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of 500m spatial resolution bands	Number of high resolution bands is stored (4bands).	－	－	－	
pixels_500	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of pixels of 500m spatial resolution band	Number of pixels including dark pixels and invalid pixels in a line of high resolution bands (Forward looking band:1-4/Backward looking band:6-9) is stored.	－	－	－	
lines_500	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of lines of 500m spatial resolution band	Number of lines in a product of high resolution bands (Forward looking band:1-4/Backward looking band:6-9) is stored.	－	－	－	
missingLines_500	Forward,Backward	OBS,CAL	1	bands_500	H5T_STD_I32LE	Number of missing lines of 500m spatial resolution band	Number of missing lines in a product of high resolution bands (Forward looking band:1-4/Backward looking band:6-9) for each band is stored.	－	－	－	
bands_1km	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of 1km spatial resolution bands	Number of low resolution bands is stored (1bands).	－	－	－	
pixels_1km	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of pixels of 1km spatial resolution band	Number of pixels including dark pixels and invalid pixels in a line of low resolution bands (Forward looking band:5/Backward looking band:10) is stored.	－	－	－	
lines_1km	Forward,Backward	OBS,CAL	1	1	H5T_STD_I32LE	Number of lines of 1km spatial resolution band	Number of lines in a product of low resolution bands (Forward looking band:5/Backward looking band:10) is stored.	－	－	－	
missingLines_1km	Forward,Backward	OBS,CAL	1	bands_1km	H5T_STD_I32LE	Number of missing lines of 1km spatial resolution band	Number of missing lines in a product of low resolution bands (Forward looking band:5/Backward looking band:10) is stored.	－	－	－	
LineAttribute_500 (Information for each line of band1-4 and 6-9)											There is no dataset if lines_500 is 0.
missingFlag	Forward,Backward	OBS,CAL	2	lines_500,bands_500	H5T_STD_I8LE	Missing line flag	In Forward/Backword looking band file, status of missing line flag for band1-4/6-9 is stored. The status is shown below. 0：No missing line 1：Missing line (No pixel available in the line) 2：Invalid (observed in other observation mode)	－	－	－	There is no dataset if lines_500 is 0.
observationTime	Forward,Backward	OBS,CAL	2	lines_500,bands_500	H5T_STRING	Line observation time (the center of exposure time) (UTC)	In Forward/Backword looking band file (band 1-4/6-9), the center of exposure time of each line (UTC) is stored. If satTimeStatusFlag is abnormal, time is corrected by the time correction information. Time format:YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string×lines_500×bands_500)	UTC	－	－	There is no dataset if lines_500 is 0.
observationTime_ContinuousTime	Forward,Backward	OBS,CAL	2	lines_500,bands_500	H5T_IEEE_F64LE	Line observation time (the center of exposure time) (seconds)	Total seconds of observationTime since 23:59:59 UTC, Dec 31, 2012.	sec	－	－	There is no dataset if lines_500 is 0.

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (3/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size Dimension	Data size Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
satTime	Forward,Backward	OBS,CAL	1	lines_500	H5T_STD_I32LE	Line satellite time	Line satellite time (sec) is stored as integer. Line satellite time (s) = GPS Time (s) −1,041,033,615(s): where GPS Time (s) is total seconds from 00:00:00 UTC, Jan 6, 1980. The time is not corrected even if satTimeStatusFlag is abnormal.	sec	−	−	There is no dataset if lines_500 is 0.
satTimeStatusFlag	Forward,Backward	OBS,CAL	1	lines_500	H5T_STD_I8LE	Satellite time system status flag	Status flag of satellite time system is stored. 0：Normal(The correction of time error is not required.) 1：Abnormal(The correction of time error is required.)	−	−	−	There is no dataset if lines_500 is 0.
observationCounter	Forward,Backward	OBS,CAL	1	lines_500	H5T_STD_I32LE	Precise observation clock (counter)	Count value of internal clock counter is stored. 1 count= 128 microseconds	−	−	−	There is no dataset if lines_500 is 0.
integrationNum	Forward,Backward	OBS,CAL	2	lines_500,bands_500	H5T_STD_I32LE	Number of integration index	In Forward(band1-4)/Backword(band 6-9) looking band file, number of integration of each line is stored.	−	−	−	There is no dataset if lines_500 is 0.
integrationTime	Forward,Backward	OBS,CAL	2	lines_500,bands_500	H5T_IEEE_F64LE	Integration time	In Forward(band 1-4)/Backword(band 6-9) looking band file, exposure time of each line is stored. This is the engineering value converting number of integration and exposure time.	sec	10	−	There is no dataset if lines_500 is 0.
LineAttribute_1km (Information for each line of band5,10)											There is no dataset if lines_1km is 0.
missingFlag	Forward,Backward	OBS,CAL	2	lines_1km,bands_1km	H5T_STD_I8LE	Missing line status flag	In Forward/Backword looking band file, status of missing line flag for band1-4/6-9 is stored. The status is shown below. 0：No missing line 1：Missing line (No pixel available in the line) 2：Invalid (observed in other observation mode)	−	−	−	There is no dataset if lines_1km is 0.
observationTime	Forward,Backward	OBS,CAL	2	lines_1km,bands_1km	H5T_STRING	Line observation time (the center of exposure time) (UTC)	In Forward/Backword looking band file (band 1-4/6-9), the center of exposure time of each line (UTC) is stored. If satTimeStatusFlag is abnormal, time is corrected by the time correction information. Time format:YYYY-MM-DDThh:mm:ss.ffffffZ (28bytes, the last 1 byte is a null terminated string×lines_1km×bands_1km)	UTC	−	−	There is no dataset if lines_1km is 0.
observationTime_ContinuousTime	Forward,Backward	OBS,CAL	2	lines_1km,bands_1km	H5T_IEEE_F64LE	Line observation time (the center of exposure time) (seconds)	Total seconds of observationTime since 23:59:59 UTC, Dec 31, 2012.	sec	−	−	There is no dataset if lines_1km is 0.
satTime	Forward,Backward	OBS,CAL	1	lines_1km	H5T_STD_I32LE	Line satellite time	Line satellite time (sec) is stored as integer. Line satellite time (s) = GPS Time (s) −1,041,033,615(s): where GPS Time (s) is total seconds from 00:00:00 UTC, Jan 6, 1980. The time is not corrected even if satTimeStatusFlag is abnormal.	sec	−	−	There is no dataset if lines_1km is 0.
satTimeStatusFlag	Forward,Backward	OBS,CAL	1	lines_1km	H5T_STD_I8LE	Satellite time status flag	Status flag of satellite time status is stored. 0：Normal(The correction of time error is not required.) 1：Abnormal(The correction of time error is required.)	−	−	−	There is no dataset if lines_1km is 0.

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (4/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
			Dimension	Size							
observationCounter	Forward, Backward	OBS, CAL	1	lines_1km	H5T_STD_I32LE	Precise observation clock (counter)	Count value of internal clock time until actual observation time is stored. 1 count= 128 microseconds	–	–	–	There is no dataset if lines_1km is 0.
integrationNum	Forward, Backward	OBS, CAL	2	lines_1km, bands_1km	H5T_STD_I32LE	Number of integration	In Forward(band 5)/Backword looking band (band 10) file, number of integration index of each line is stored.	–	–	–	There is no dataset if lines_1km is 0.
integrationTime	Forward, Backward	OBS, CAL	2	lines_1km, bands_1km	H5T_IEEE_F64LE	Integration time	In Forward (band 5)/Backword (band 10) looking band file, exposure time of each line is stored. Engineering value conversion parameters from number of integgration index.	sec	10	–	There is no dataset if lines_1km is 0.
ImageData (CAI-2 data)											
band1	Forward	OBS, CAL	2	lines_500, pixels_500	H5T_STD_I16LE	Band 1 image data	Pixel digital values for line and pixel are stored. 1st dimension is line, 2nd dimension is pixel.	–	–	-998; -999	Details of invalid value -999 : missing pixel -998 : except for observation mode There is no dataset if lines_500 is 0.
band2	Forward	OBS, CAL	Same as band1_Image. This item is only for Forward looking bands.								
band3	Forward	OBS, CAL	Same as band1_Image. This item is only for Forward looking bands.								
band4	Forward	OBS, CAL	Same as band1_Image. This item is only for Forward looking bands.								
band5	Forward	OBS, CAL	2	lines_1km, pixels_1km	H5T_STD_I16LE	Band 5 image data	Pixel digital values for line and pixel are stored. 1st dimension is line, 2nd dimension is pixel.	–	–	-998; -999	Details of invalid value -999 : missing pixel -998 : except for observation mode There is no dataset if lines_1km is 0.
band6	Backward	OBS, CAL	Same as band1_Image. This item is only for Backward looking bands.								
band7	Backward	OBS, CAL	Same as band1_Image. This item is only for Backward looking bands.								
band8	Backward	OBS, CAL	Same as band1_Image. This item is only for Backward looking bands.								
band9	Backward	OBS, CAL	Same as band1_Image. This item is only for Backward looking bands.								
band10	Backward	OBS, CAL	Same as band5_Image. This item is only for Backward looking bands.								
GeometryAttribute (Geometric information for standard band)											
stdBand	Forward, Backward	OBS, CAL	1	1	H5T_STD_I32LE	Standard band No.	In Forward looking band file, stdBand is any one of band 1-4. In Backward looking band file, stdBand is any one of band 6-9.	–	–	–	
subsetPixelInterval	Forward, Backward	OBS, CAL	1	1	H5T_STD_I32LE	Interval of subset pixel (in pixel direction)	Interval of subset pixel (in pixel direction of stdBand) is stored.	–	–	–	
subsetLineInterval	Forward, Backward	OBS, CAL	1	1	H5T_STD_I32LE	Interval of subset pixel (in line direction)	Interval of subset pixel (in line direction of stdBand) is stored.	–	–	–	

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (5/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size Dimension	Data size Size	Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
subsetNumPixels	Forward, Backward	OBS, CAL	1	1	H5T_STD_I32LE	Number of subset pixel (in pixel direction)	Number of subset pixel in pixel direction is stored.	–	–	–	
subsetNumLines	Forward, Backward	OBS, CAL	1	1	H5T_STD_I32LE	Number of subset pixel (in line direction)	Number of subset pixel in line direction is stored.	–	–	–	
subsetPixel	Forward, Backward	OBS, CAL	1	subsetNumPixels	H5T_STD_I32LE	Pixel No. of subset pixel in standard band of original image size	Pixel No. of subset pixel in standard band of original image size is stored.	–	–	-999	
subsetLine	Forward, Backward	OBS, CAL	1	subsetNumLines	H5T_STD_I32LE	Line No. of subset pixel in standard band of original image size	Line No. of subset pixel in standard band of original image size is stored.	–	–	-999	There is no dataset if subsetNumLines is 0.
ImageGeometry											
longitude	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Longitude at the line exposure time	Longitude for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. -180 < longitude ≤ 180	deg	10	-999	There is no dataset if subsetNumLines is 0.
latitude	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Latitude at the line exposure time	Latitude for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. -90 ≤ latitude ≤ 90	deg	10	-999	There is no dataset if subsetNumLines is 0.
viewZenith	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Sensor view zenith angle at the observation point	Incident angle of sensor view vector for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. 0≦ viewZenith ≦90	deg	10	-999	There is no dataset if subsetNumLines is 0.
viewAzimuth	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Azimuth directoion of sensor view vector at the observation point	Azimuth direction of sensor view vector for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. 0≦ viewAzimuth ＜360	deg	10	-999	There is no dataset if subsetNumLines is 0.
scatteringAngle	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Scattering angle	Scattering angle for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. 0≦ scatteringAngle ≦180	deg	10	-999	There is no dataset if subsetNumLines is 0.
solarZenith	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Solar zenith angle at the observation point	Solar zenith angle for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. 0 ≦solarZenith≦180	deg	10	-999	There is no dataset if subsetNumLines is 0.
solarAzimuth	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Solar azimuth angle at the observation point	Solar azimuth angle for each subset pixel of standard band image is stored except for calibration product and lunar calibration product. 0≦solarAzimuth＜360	deg	10	-999	There is no dataset if subsetNumLines is 0.
solarDistance	Forward, Backward	OBS only	2	subsetNumLines, subsetNumPixels	H5T_IEEE_F64LE	Distance between sun and the observation point	Distance from solar to obserbation point for each subset pixel of standard band image is stored except for calibration product and lunar calibration product.	AU	10	-999	There is no dataset if subsetNumLines is 0.
lunarSatelliteSolar_angle	Forward, Backward	OBS, CAL	1	subsetNumLines	H5T_IEEE_F64LE	Angle between lunar to satellite vector and soloar to satellite vector	Angle between lunar to satellite vector and soloar to satellite vector is stored. 0 ≤ lunarSatelliteSolar_angle < 180	deg	10	-999	There is no dataset if subsetNumLines is 0.
SatelliteGeometry											
satPos_ECR	Forward, Backward	OBS, CAL	2	subsetNumLines, 3	H5T_IEEE_F64LE	Satellite position (ECR(WGS84))	Satellite position in ECR(WGS84) for each sample and line exposure time of standard band image is stored.	km	10	–	There is no dataset if subsetNumLines is 0.
satVel_ECR	Forward, Backward	OBS, CAL	2	subsetNumLines, 3	H5T_IEEE_F64LE	Satellite velocity (ECR(WGS84))	Satellite velocity in ECR(WGS84) for each sample and line exposure time of standard band image is stored.	km/s	10	–	There is no dataset if subsetNumLines is 0.
satPos_ECI	Forward, Backward	OBS, CAL	2	subsetNumLines, 3	H5T_IEEE_F64LE	Satellite position (ECI(TOD))	Satellite position in ECI(TOD) for each sample and line exposure time of standard band image is stored.	km	10	–	There is no dataset if subsetNumLines is 0.

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (6/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
			Dimension	Size							
satVel_ECI	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Satellite velocity (ECI(TOD))	Satellite velocity in ECI(TOD) for each sample and line exposure time of standard band image is stored.	km/s	10	–	There is no dataset if subsetNumLines is 0.
satArgLat	Forward,Backward	OBS,CAL	1	subsetNumLines	H5T_IEEE_F64LE	Argument of latitude	Argument of latitude of observation time is stored. 0≦satArgLat<360	deg	10	–	There is no dataset if subsetNumLines is 0.
satOrbitPrecision	Forward,Backward	OBS,CAL	1	subsetNumLines	H5T_STRING	Precision of satellite orbit	Orbit data type for satPos_ECR/ECI, satVel_ECR/ECI is stored. "OnBoard":Onboard orbit data "Predicted":Predicted orbit data "Determined":Determined orbit data (The above number of charcter plus the delimiter × subsetNmLines)	–	–	–	There is no dataset if subsetNumLines is 0.
satAtt	Forward,Backward	OBS,CAL	2	subsetNumLines,4	H5T_IEEE_F64LE	Satellite attitude (ECI(J2000)) in pseudo satellite-fixed coordinate	Satellite attitude data for each sample and line exposure time is stored as quaternion at ECI(J2000). q0 is scalar component and q1, q2, and q3 are i, j, and k, respectively.	–	10	–	There is no dataset if subsetNumLines is 0.
satRPY	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Satellite Attitude Roll/Pitch/Yaw	Satellite attitude for each sample and line exposure time is stored as roll, pitch, and yaw angles. satRPY[subsetNumLines][b] b=0:roll b=1:pitch b=2:yaw -180 < satRPY[subsetNumLines][b]≦ 180	deg	10	–	There is no dataset if subsetNumLines is 0.
yawSteeringFlag	Forward,Backward	OBS,CAL	1	subsetNumLines	H5T_STD_I8LE	Yaw steering flag	Yaw steering flag indicates the operation of yaw steering. yawSteeringFlag[subsetNumLines] 0: Not execute(OFF) 1: Execute(ON) 2: Invalid due to data loss and so on	–	–	2	There is no dataset if subsetNumLines is 0.
satAttInterpolationMethodFlag	Forward,Backward	OBS,CAL	1	subsetNumLines	H5T_STD_I8LE	Satellite attitude interpolation method flag	Interpolation method for calculating satellite attitude is stored. 0:Interpolation 1:Extrapolation	–	–	–	There is no dataset if subsetNumLines is 0.
satAttInterpolationQualityFlag	Forward,Backward	OBS,CAL	1	subsetNumLines	H5T_STD_I8LE	Satellite attitude Interpolation quality flag	Interpolation quality of calculating satellite attitude is stored. 0:Good(Interval of source data for interpolation is fine sufficiently. Thus, interpolation value is high accuracy.) 1:Poord(Interval of source data for interpolation is rough. Thus, interpolation value is low accuracy.)	–	–	–	There is no dataset if subsetNumLines is 0.
satToECR_Matrix	Forward,Backward	OBS,CAL	2	subsetNumLines,9	H5T_IEEE_F64LE	vCoordinate transformation matrix from satellite-fixed to ECR(WGS84)	Coordinate transformation matrix convert from satellite-fixed coordinate to ECR(WGS84) are stored in the following order: (0, 1, 2) (3, 4, 5) (6, 7, 8)	–	10	–	There is no dataset if subsetNumLines is 0.
SolarGeometry											
solarPos_ECR	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Apparent solar position at the line exposure point (ECR(WGS84))	Apparent solar position in ECR(WGS84) for each sample line is stored.	km	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
solarVel_ECR	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Apparent solar velocity at the line exposure point(ECR(WGS84))	Apparent solar velocity in ECR(WGS84) for each sample line is stored.	km/s	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
solarPos_ECI	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Apparent solar position at the line exposure point(ECI(TOD))	Apparent solar position in ECI(TOD) for each sample line is stored.	km	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
solarVel_ECI	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	Apparent solar velocity at the line exposure point (ECI(TOD))	Apparent solar velocity in ECI(TOD) for each sample line is stored.	km/s	10	(0,0,0)	There is no dataset if subsetNumLines is 0.

Table 6-2 Dataset definition of CAI-2 L1A forward/backward looking band file (HDF5) (7/7)

Group Path/Dataset Name	Forward/Backward	Observation/Caliration mode	Data size		Data Type	Dataset Name	Explanation (Format)	Unit	Significant digit	Invalid Value	Notes
			Dimension	Size							
LunarGeometry											
lunarPos_ECR	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	True lunar position at the line exposure point(ECR(WGS84))	True lunar position in ECR(WGS84) for each sample line is stored.	km	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
lunarVel_ECR	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	True lunar velocity at the line exposure point(ECR(WGS84))	True lunar velocity in ECR(WGS84) for each sample line is stored.	km/s	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
lunarPos_ECI	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	True lunar position at the line exposure point(ECI(TOD))	True lunar position in ECI(TOD) for each sample lineis stored.	km	10	(0,0,0)	There is no dataset if subsetNumLines is 0.
lunarVel_ECI	Forward,Backward	OBS,CAL	2	subsetNumLines,3	H5T_IEEE_F64LE	True lunar velocity at the line exposure point(ECI(TOD))	True lunar velocity in ECI(TOD) for each sample line is stored.	km/s	10	(0,0,0)	There is no dataset if subsetNumLines is 0.