GOSAT / IBUKI Data Users Handbook

1st Edition

March 2011

Japan Aerospace Exploration Agency
National Institute for Environmental Studies
Ministry of the Environment

Preface

At the present stage of civilization, we are facing the big issue of global warming. We may suffer a drastic environmental change in less than a few centuries if no effective measures are taken. Efforts have been made worldwide to reduce greenhouse gases. Japan also has a strong interest in reducing the gases and seeks steady means to measure the gas concentration.

However, only a limited number of observation points, dispersed not uniformly over the globe, are available on the ground to measure greenhouse gases. In order to observe the greenhouse gases (carbon dioxide and methane, principally) concentration distribution over the whole globe periodically through a common measuring method, Greenhouse gases Observing SATellite (GOSAT), so called “Ibuki”, project was started by Japan Aerospace eXploration Agency, National Institute for Environmental Studies, and Ministry Of the Environment to launch the satellite on the date of January 23rd, 2009. By accumulating the concentration distribution data and the estimated uptake and release of greenhouse gases, carbon dioxide and/or methane variation will be monitored and climate change in the future may come into the scope of prediction.

The present handbook is meant for general users who are interested in using GOSAT data and/or such users who have already been using the data with further interest for better understanding of the data. GOSAT data are provided free of charge not only to the limited number of governmental organization or researchers but also to the people in general. However, no document has been provided for the users to clarify systematically the overall of GOSAT with much emphasis on the outcome from the satellite in service.

This handbook provides information necessary for GOSAT users, such as the naming rule of the products, product format, and algorithmic explanation on the products in a handy booklet to allow users to access information of their needs with ease. This handbook, intended for introductory use rather than for specialists, only describes characteristics of GOSAT standard products with expressions as easy as possible. For further information beyond the scope of this document, please refer to the bibliographies recommended by the handbook.

We expect GOSAT data users, with the help of this handbook, through the extensive use of GOSAT data, to clarify the global distribution and the temporal change of the greenhouse gases, and to accumulate knowledge newly acquired about the carbon circulation mechanism on the whole globe, and its influence on the climate change, thereby contributing to the protection against global warming and environmental conservation.

The Great East Japan Earthquake struck on March 11 during the process of creating this handbook. However, both GOSAT satellite itself and Japan Aerospace eXploration Agency’s ground system have kept the operation without damage. The data processing facility of National Institute for Environmental Studies was almost restored at the end of March.

GOSAT / IBUKI Data Users Handbook

Contents

GOSAT / IBUKI Data Users Handbook
List of Tables and Figures

[Tables]

[Figures]

Chapter 1 Introduction

1.1 Purpose

This handbook intends to make the GOSAT (Greenhouse gases Observing SATellite, so-called IBUKI) data be acknowledged by users in general and provides the users with information about the GOSAT standard products as well as the background knowledge of the spacecraft, sensors, ground systems, and so on; thereby promoting a wide use of the data products and serving users with convenience.

1.2 Scope and Composition

The present handbook is made of eight chapters with appendices as shown below.

Chapter 1	:	Describes the purpose, scope, and composition of the present document the chapter also summarizes GOSAT mission.
Chapter 2	:	Briefly describes GOSAT mission.
Chapter 3	:	Briefly describes GOSAT mission operations.
Chapter 4	:	Describes GOSAT ground systems.
Chapter 5	:	Describes GOSAT ground system operations.
Chapter 6	:	Describes specifications of GOSAT products and processing algorithm for the products.
Chapter 7	:	Explains the way the GOSAT products are provided.
Chapter 8	:	Point of contact for the Handbook and GOSAT data products
Appendices	:	Acronyms, terminology, and bibliography

Notes:

The product specifications and processing algorithm are described here to give readers essential perspectives as a whole; for details, please refer to the documents listed in the appendix. “Algorithm Theoretical Basis Documents (ATBD)”, “Product format descriptions documents”, to name a few.

The data delivery service defined in chapter 7 deals with GOSAT data products provided by National Institute for Environmental Studies (hereafter called NIES) for general users[1].

[1] Please refer to 7.2.2 for the kinds of GOSAT users including general users.

1.3 GOSAT Mission Outline

GOSAT observes carbon dioxide and methane – two major green-house effect gasses – from space, a first satellite in the world for measuring the density of the gasses. It was launched on January 23, 2009, to conduct routine observation since April 2009 after initial checkouts held in February through March. The expected mission life is five years. (see Appendix A2 (5))

GOSAT data, being analyzed, serve to know how the carbon dioxide and methane are distributed over the globe; and the green-house gas accounting – when and wherefrom the gasses are discharged or absorbed – is made to know its geographical distribution and seasonal and/or yearly changes. Such knowledge shall give deeper understanding in the science of behavior of carbon dioxide and methane gasses – agent to cause global warming. The knowledge also serves as a basis for enhancing climate change predictions in the future, and for devising anti-warming means such as carbon discharge reduction policy. GOSAT project is promoted under the cooperative support of Ministry of the Environment (hereafter called MOE), National Institute for Environmental Studies (NIES), and Japan Aerospace eXploration Agency (hereafter called JAXA). Fig. 1.3-1 shows the role of the three organizations.

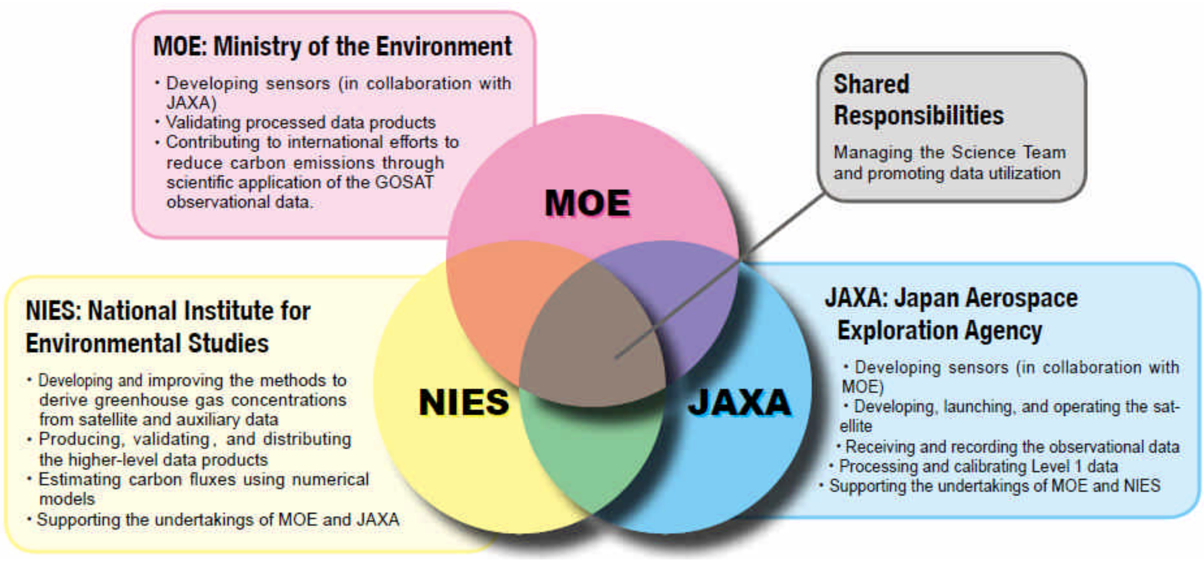


Fig. 1.3-1 Roles of organizations in GOSAT project

Chapter 2 GOSAT Spacecraft Outline

2.1 Configuration of the Spacecraft

GOSAT is an Earth observation satellite to measure the greenhouse effect gasses, carbon dioxide and methane in particular. The satellite was launched by H-IIA launch vehicle on January 23rd, 2009 to the sun-synchronous sub-recurrent orbit having an approximate altitude of 666 km. Fig. 2.1-1 shows a schematic diagram of GOSAT, and Table 2.1-1 lists up the major specifications.

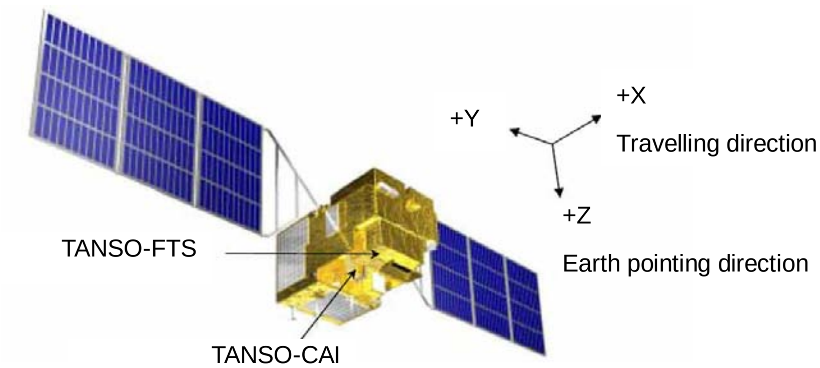


Fig. 2.1-1 GOSAT

Table 2.1-1 GOSAT major specifications

Entry	Specifications
Dimension	Frame body : X (height) 3.7m Y (width) 1.8m Z (depth) 2.0m (projections ignored) Paddle ends distance 13.7m
Mass	1,750kg
Power supply	3.8kw (at the end of mission life)
Mission life	5 years
Launch date	January 23, 2009

Earth observation mission oriented instruments GOSAT is equipped with are “Thermal And Near infrared Sensor for carbon Observation - Fourier Transform Spectrometer” (hereafter called TANSO-FTS or FTS) and “Thermal And Near infrared Sensor for carbon Observation Cloud and Aerosol Imager” (hereafter called TANSO-CAI or CAI). Other mission oriented instruments are “TEchnical Data

Acquisition equipment" (hereafter called TEDA) and monitoring CAMera (hereafter called CAM). Fig. 2.1-2 shows GOSAT system configuration.

TANSO-FTS is a Fourier transform spectrometer having three bands of observation wavelength in ShortWave InfraRed frequencies (hereafter called SWIR) and one band in Thermal InfraRed frequencies (hereafter called TIR). This gives 7 channels of observed data simultaneously acquired, six of which are made of 2 polarized components (P-polarization and S-polarization) of respective SWIR three bands, and TIR the remaining one.

TANSO-CAI is a push broom type optical sensor equipped with one-dimensionally arrayed detectors and three telescopes to have four bands of observation wavelengths ranging from ultraviolet to short wavelength infrared. Spatial resolution in nadir view, with an observation scan width of about 1,000km, is about 500m for bands 1 through 3, and about 1,500m for band 4 with 750km of scan width.

Data captured by TANSO-FTS and/or TANSO-CAI are processed in Mission Data Handling System (hereafter called MDHS) and recorded into Mission Data Processor (hereafter called MDP) as per every Application Process ID (hereafter called APID). The recorded data are played back above receiving stations to transmit them to the ground facilities using Direct Transmission system (hereafter called DT) through X-band channel. The MDP, the recording apparatus, uses 48GB (BOL:16GByte×3) semiconductor memories.

Robustness is secured for the mission data transmission by preparing a route to bypass the MDP memory in case the memory bus meets some trouble. The data for the route are made in the sensors by branching off the same mission data; the data having bypassed the memory then multiplexed in MDHS as usual and transmitted to the ground stations. The data thus prepared will stay not transmitted under normal conditions; however in case of the memory bus failure they are sent replacing the playback data mentioned above.

- GOSAT
  - Mission instruments
    - Fourier Transform Spectrometer (TANSO-FTS)
    - Cloud and Aerosol Imager (TANSO-CAI)
      (for observation mission)
    - Technical Data Acquisition equipment (TEDA)
    - Monitor camera (CAM)
      (for mission in general)
    - Mission Data Handling System (MDHS)
    - Direct Transmission (DT)
      (for mission data transfer)
  - BUS instruments
    - Telemetry Tracking & Control (TT&C)
    - Electric Power System (EPS)
    - Solar Paddle (PDL)
    - Attitude & Orbit Control System (AOCS)
    - Structure (STR)
    - Thermal Control System (TCS)
    - Reaction Control System (RCS)
    - Integration Hardware (INT)

Fig. 2.1-2　GOSAT System configuration

2.2　Mission Instruments Outline

This section explains briefly about the two mission instruments installed on GOSAT for Earth observation.

2.2.1　TANSO-FTS

(1) Outline

TANSO-FTS performs spectroscopic observation on both short wavelength infrared sunlight reflected by the surface of the earth after it has come through the atmosphere, and thermal infrared light radiated from the atmosphere. Fig. 2.2-1 shows the outside view of TANSO-FTS, while Table 2.2-1 lists up its specifications. Calculations based on observations of 2.0μm range CO_2 absorption and of 1.6μm range CO_2 and/or CH_4 absorption give an air-column quantity[2], while its altitudinous

[2] Air-column quantity: Total amount of gasses in a vertical column having unit cross-section (number of molecules per unit area)

profile may be calculated from observations of thermal infrared range. Fourier interferometer is used for spectroscopy which may provide high resolution of 0.2cm^{-1} over a wide span of wavelength. In normal operations, one interferogram is acquired every four seconds. Orientating mechanism about the Along Track (hereafter called AT)[3] axis and Cross Track (hereafter called CT) axis[4] allow the sensor to scan in the CT direction, to point to the sunglint spot and/or predetermined locations, and to keep pointing a place during one whole interferogram capturing.

The Fourier interferometer is a double-cornered cubic type, while a long-life semiconductor laser of 1.31µm wavelength is used for sampling in order to realize the mission life of five years. The detectors make use of Si, InGaAs, and PC-MCT, where a polarizing beam splitter is used with the bands 1 through 3 to observe the two polarized beams simultaneously.

On orbit calibration is conducted for SWIR using solar irradiance diffused by a diffuser plate, and for TIR sensitivity using a blackbody. Calibration making use of the moon is also conducted. Further, semiconductor laser beam of 1.55µm wavelength is utilized to calibrate the instrument functions for the equipment.

TANSO-FTS conducts geometrical evaluation using a view monitoring camera installed in the TANSO-FTS and GCPs on the ground.

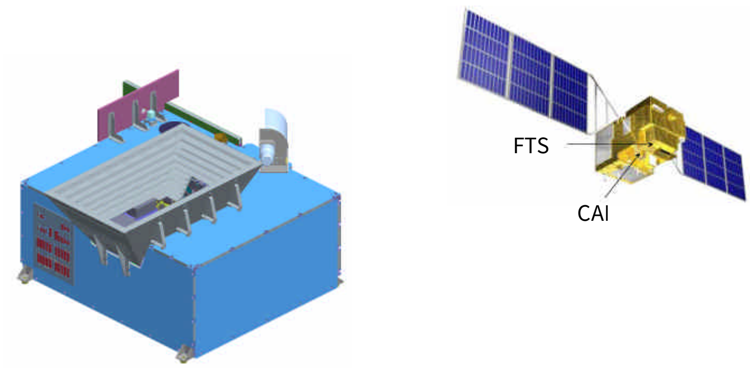


Fig. 2.2-1 Outside view of TANSO-FTS

[3] Along Track: The direction a spacecraft travels, a coordinate axis forming the spacecraft-fixed coordinates.

[4] Cross Track: A direction perpendicular to along-track, an axis to form the spacecraft-fixed coordinates.

Table 2.2-1　TANSO-FTS Specifications

Pointing mechanis	Configuration	two-axes pointing (wholly redundant)			
	Scanning	CT (±35 deg）　AT (±20 deg)			
	View	IFOV <10.5 km　scan width 790 km			
Interferogram	Scanning frequency	0.25, 0.5, or 1 interferogram/second			
		SWIR			TIR
	Band	1	2	3	4
	Polarization	applicable	applicable	applicable	N/A
	Wavenumbers (cm^{-1})	12,900 -13,200	5,800 - 6,400	4,800 - 5,200	700 -1,800
	Wavelength (μm)	0.75 - 0.78	1.56 -1.72	1.92 - 2.08	5.5 -14.3
	Resolution (cm^{-1})	0.2 cm^{-1} (scan on both sides) (MOPD +/-2.5 cm)			
	Detector	Si	InGaAs		PC-MCT
	On-orbit calibration	for sensitivity: solar irradiance, deep space, the moon for instrument functions: semiconductor laser			blackbody, deep space

(2) Observation procedure

Observations are conducted to follow the steps a. to g. described below; while Fig. 2.2-2 shows schematically how the optical system works, wherein symbols a to g correspond to the itemized paragraphs respectively.

a. Introduce the light beams to capture into sensors by orientating the pointing mechanism toward the object to observe. The bands 1 through 3 capture the sunlight reflected from the atmosphere and the surface of the earth, while the band 4 captures the heat radiated from the atmosphere and the earth’s surface.

b. The beam-splitter of a Fourier interferometer splits the captured beams into two directions.

c. The beams split into different directions are added once again to interfere each other after travelling different lengths of optical path. The interference pattern thus acquired is called an interferogram. (see Fig. 2.2-3 (a))

d. The input observation light thus made interfered by the Fourier interferometer is concentrated into a slit, thereby forming a view field in common to all the bands (15.8mrad or 10.5km on the surface of the earth).

e. Observation light beams parallelized by optical equipment including the slit are separated, by dichroic filter placed one after another, into bands of frequencies ranging from short waves to longer ones.

f. The band-separated light beams go through a band filter prepared for each band, by which extra signals outside the band frequencies be eliminated, and enters into a detector; while the beams of band 1 to 3 are split into two polarized light beams (P-polarization and S-polarization) by a polarization beam splitter before entering into the detector.

g. The detector, working as a photoelectric converter, converts the observation signals (interferogram) to electric signals, and let them sent down to ground stations.

h. Information is extracted from the data captured on the ground and Fourier-converted to get a spectrum of the observed light. (see Fig. 2.2-3 (b))

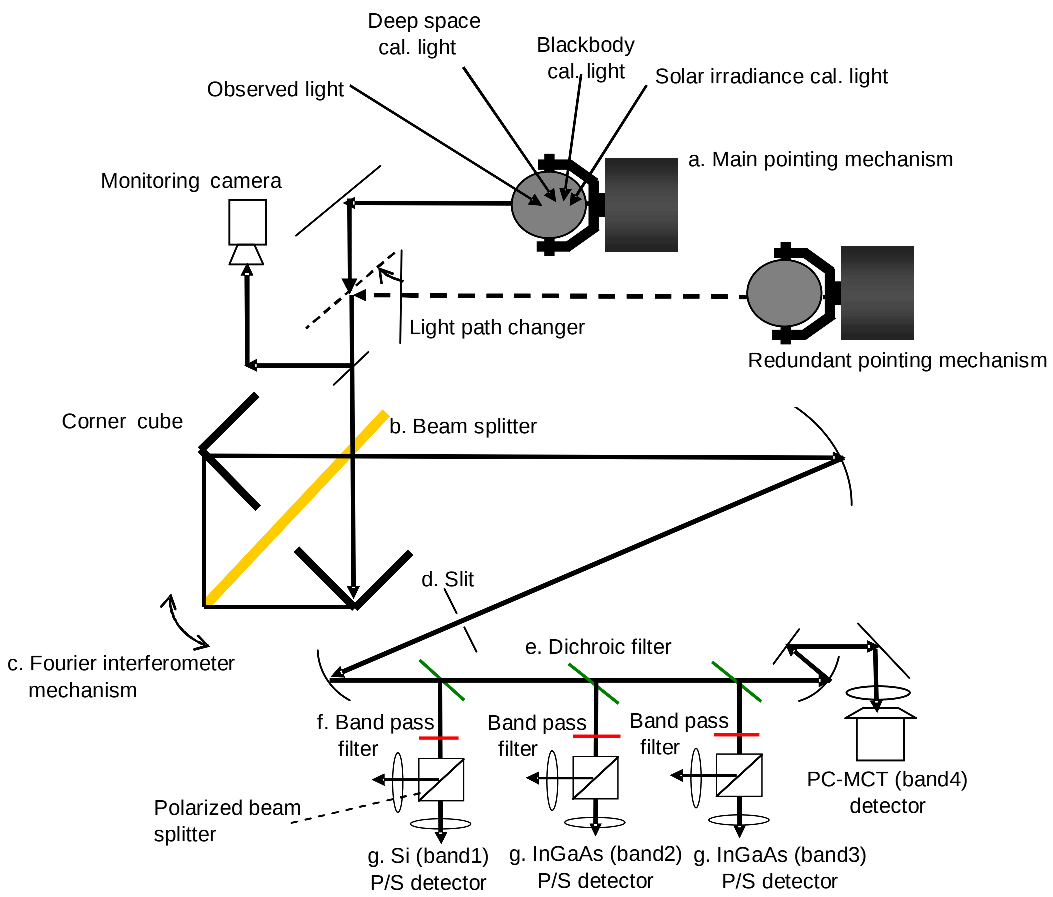


Fig. 2.2-2 Schematic diagram of TANSO-FTS optical systems

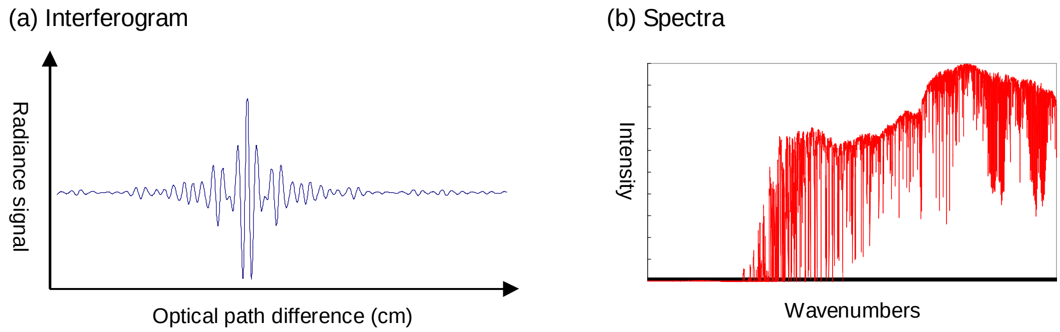


Fig. 2.2-3　Data served by TANSO-FTS

2.2.2　TANSO-CAI

(1) Outline

TANSO-CAI is a push-broom type optical sensor having four bands of frequencies ranging from ultraviolet to shortwave infrared. Fig. 2.2-4 shows the outside view of TANSO-CAI, while Table 2.2-2 lists up its specifications.

CAI, a sensor auxiliary to FTS, captures a picture image of the ground covering the area observed by FTS. The CAI data are used to evaluate the validity of FTS data and are used to correct them. When CAI data detect some dense cloud in the view of FTS, FTS data may be discarded depending on the information derived from CAI. Further, when CAI data detect aerosol and/or a cirrus cloud, FTS data are modified using the aerosol and cirrus cloud attributes (characteristics and optical thickness) estimated by the CAI data.

CAI, being equipped with electronic scanning imagers for a plurality of frequency bands ranging from ultraviolet, through visible, to shortwave infrared, will conduct highly accurate observation of cirrus clouds in high altitudes and the spread of aerosol including the ones over land areas. It has a wide span of observation width of 1,000km with ±35deg CT view angles. Band 1, 2, or 3 exhibits a spatial resolution of about 500m at nadir, while band 4 does show about 1,500m.

Geometrical evaluation for TANSO-CAI is done making use of GCP (Ground Control Point) on the ground.

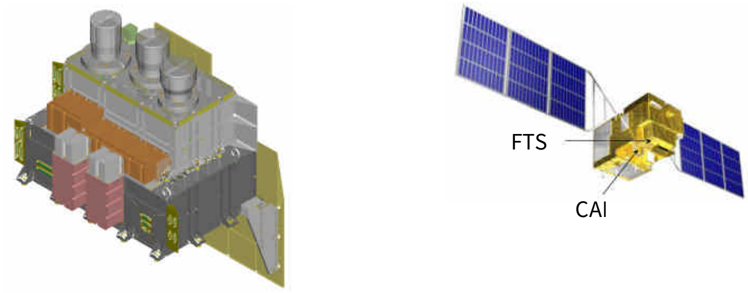


Fig. 2.2-4 Outside view of TANSO-CAI

Table 2.2-2 TANSO-CAI specifications

	Band 1	Band 2	Band 3	Band 4
Central wavelength (μm)	0.38	0.674	0.87	1.6
Wavelength band width (nm)	20	20	20	90
Spatial resolution (km) (at nadir)	0.5	0.5	0.5	1.5
Number of elements	2,056	2,056	2,056	512

(2) Observation method

TANSO-CAI composes its images from signals provided by CCD elements arranged in line; these elements are prepared for each of the four bands of observation signals. Fig. 2.2-5 shows schematically how the CAI observation is conducted.

Conducting daytime observations on sunlit areas, CAI covers the whole globe in three days with spatial resolution of 500m for the bands 1 to 3, and of 1,500m for the band 4.

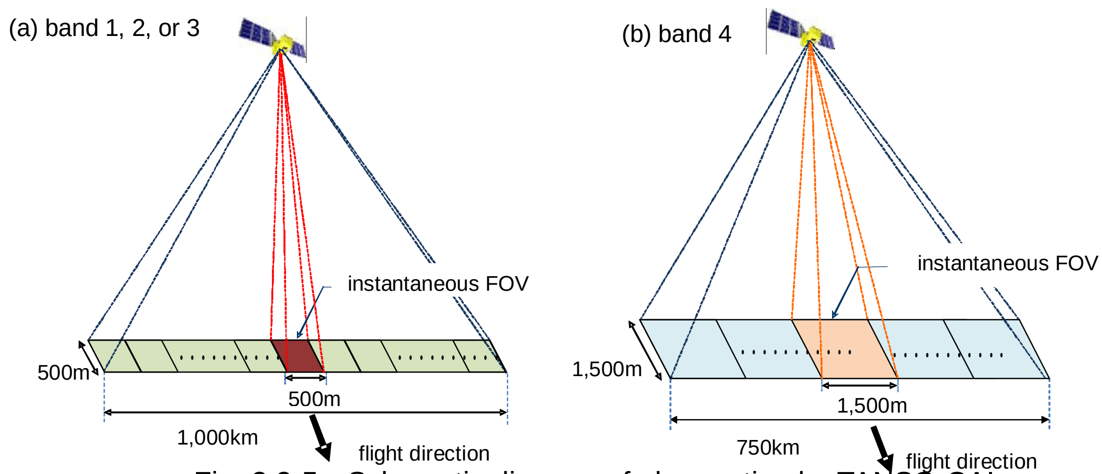


Fig. 2.2-5 Schematic diagram of observation by TANSO-CAI

Chapter 3 GOSAT Mission Operation Outline

3.1 GOSAT Orbital Operations

3.1.1 Orbit Parameters

Table 3.1-1 shows GOSAT nominal orbit parameters.

Table 3.1-1 GOSAT nominal orbit parameters

Parameter	Value
Orbit type	sun-synchronous sub-recurrent orbit
Revolutions per day	14+2/3 revolutions/day
Days of recurrence	3 days
Altitude	665.96km
Eccentricity	0.0
Inclination	98.06 degrees
Period	98.1 minutes approximately
Revolutions for a recurrence	44 revolutions
Local sun time at crossing the descending node	13:00 ± 15 minutes

3.1.2 Orbit Control and Keeping

GOSAT has an attitude-orbit-control system that may keep its orbit autonomously by monitoring how accurate the orbit is and by planning enough frequency of maneuvers to keep its orbit adjusted. As a result, sun synchronous sub-recurrent orbit is kept with local descending time, altitude, period, and the like kept nearly constant. This allows GOSAT to conduct sensor observations recurrently with a recurrence error of less than ±2.5km.

Based on GPS (Global Positioning System) data, GOSAT automatically calculates such maneuver parameters as injection strength, duration, and injection timing of the fuel; the parameters thus calculated onboard are sent down to ground stations in telemetry data. The ground station sends a permission command for the planned autonomous orbit maneuvers after it has confirmed that the maneuver parameters are reasonable.

As of December, 2010, orbit maneuvers are conducted once in 6 to 9 days.

3.2 TANSO-FTS / TANSO-CAI Operations

This section describes the functions of TANSO-FTS and TANSO-CAI, and explains how they are utilized in operation.

3.2.1 TANSO-FTS / TANSO-CAI, Functions and Performance

(1) Functions of TANSO-FTS

a. Observes the atmosphere by SWIR using frequencies ranging from visible to shortwave infrared, while TIR conducts the observation using thermal infrared frequencies.

b. Observation direction is controllable by a pointing mechanism equipped with two axes of rotation (AT-axis, CT-axis) to allow observation as follows.

1) Scans along the CT direction with intervals of a predetermined angle.
2) In routine observation, observes predetermined number of points scanning 1, 3, 5, 7, or 9 points along the CT direction; the observed points will form a grid-like pattern on the earth's surface when the scan is repeated at an interval along the AT direction.
3) Keeps pointing the same place during the whole capture of an interferogram which may last 1 to 4 seconds (exposure time).
4) In order to improve Signal to Noise Ratio (SNR), may observe a same place repeatedly to sum the observed data up (3 times of repetition, or only once with no repetition).
5) Points to a specified place or a sunglint for observation (sunglint: a place where the ocean surface reflects sunlight, like a mirror, toward the spacecraft).

c. Observes a same place every three recurrent days.

d. Conducts on-orbit calibration listed below.

1) The solar irradiance calibration for SWIR, and blackbody calibration for TIR.
2) Deep space calibration for both SWIR and TIR.
3) Orients the GOSAT +Z axis (usually pointing to the earth) to the moon and conducts annual calibration of sensitivity using the sunlight reflected by the moon.

(2) Functions of TANSO-CAI

a. Captures 1,000km observation width of images of the earth's surface with spatial resolution of 0.5 to 1.5km.

b. Serves data to estimate an amount of clouds and aerosol in the atmosphere observed; based on this estimation, FTS data may be corrected or discarded.

c. Orients the GOSAT +Z axis (usually pointing to the earth) to the moon and conducts annual calibration of sensitivity using the sunlight reflected by the moon.

3.2.2 Operation Mode

Table 3.2-1 lists up the operation modes of TANSO-FTS, while the transition among the modes is shown in Fig. 3.2-1 TANSO-FTS operation mode transition diagram. TANSO-FTS works in observation mode I or in specific observation mode, and calibrates itself in calibration modes.

For TANSO-CAI, Table 3.2-2 lists up its operation modes, while the transition among the modes is shown in Fig. 3.2-2. TANSO-CAI usually works in observation mode, and calibrates itself in calibration modes.

Transition time between modes will be minimized in so far as instruments are kept in safer conditions.

Table 3.2-1 TANSO-FTS operation mode

Operation mode	Outline	Remarks
All off mode	This mode is set effective right after the installation into the spacecraft on the ground, and kept till the primary power supply is switched on (100 minutes after the launch). In Super Light Load Mode (S-LLM), a mode for GOSAT to stay alive with serious damage, the sensor will be kept in this All-off-Mode. S-LLM demands least amount of power consumption still lower than Light Load Mode (LLM).	
Standby mode I	A mode to satisfy the conditions demanded by Observation Mode I. The detectors for shortwave infrared and thermal infrared are cooled down.	
Standby mode II	A mode to satisfy the conditions demanded by Observation Mode II. The shortwave infrared detector is cooled down.	
Refrigerator standby	A mode to satisfy the conditions to start the refrigerator.	
Refrigerator cools-down mode	Cool the thermal infrared detector with the signal processer and refrigerator switched on; used in the initial operational phase; while the refrigerator is basically kept on.	
Light Load Mode I (LLM-I)	A mode to keep TANSO-FTS in a state free from any defects, failures, or unrecoverable degradation in case GOSAT is placed in abnormal attitude and/or power supply is out of order; wherein the refrigerator, interferometer mechanism, and pointing mechanism are switched off while survival heaters and command reception circuits are kept on. The LLM-I is set effective when the primary power supply is switched on after the launch.	
Light Load Mode II (LLM-II)	The survival hearer for the refrigerator radiator is set off while other survival heaters and command reception circuits are kept on. This mode may be applied in case a wing of the solar paddle pair is out of order.	

Operation mode		Outline	Remarks
Observation mode I	Daytime observation	Conduct observations using shortwave infrared (SWIR) and thermal infrared (TIR); black-body calibration and deep space calibrations are also conducted.	routine observation
	Nighttime observation	Conduct observations using thermal infrared (TIR); black-body calibration and deep space calibrations are also conducted.	routine observation
Observation mode II		Stop operating thermal infrared (TIR) and freeze pointing mechanism when power supply is lowered. Observation using TANSO-FTS is restricted to 10 minutes per revolution while Standby Mode II is supposed to apply for the rest of hours, and TANSO-CAI will be kept in All off Mode.	non-routine observation
Diagnostic mode		Diagnose the refrigerator and remove contaminations off the cooling device if necessary.	as required
Specific observation mode		Observe specific places such as sites for verification and points along a pipeline. Sun glint points are also included.	routine observation
Calibration mode	Solar irradiance calibration	Perform calibration using the sunlight dissipated by the sun irradiance diffuser plate at the time just before the ground surface is illuminated by the sun.	once per revolution
	Lunar calibration	Calibrate sensitivity using the sunlight reflected from the moon at its highest average brightness while the spacecraft orient its +Z axis to the moon.	about once a year
	Instrument function calibration	Calibrate instrument functions using the laser beams emitted by the laser diode installed in the sensor.	about once a month
	Electrical calibration	Calibrate the signal processor including the analog signal processing unit by applying standard signal voltage.	about once a month

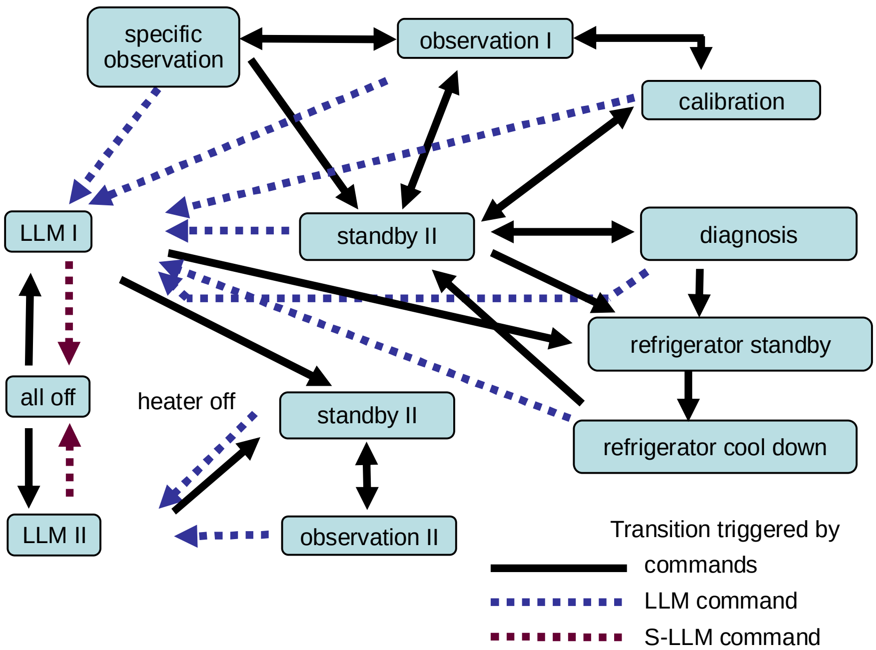


Fig. 3.2-1 TANSO-FTS operation mode transition diagram

Table 3.2-2 TANSO-CAI operation mode

Operation mode		Outline	Remarks
All off mode		This mode is set effective right after the installation into the spacecraft on the ground, and kept till the primary power supply is switched on (100 minutes after the launch). A mode for GOSAT to stay alive with serious damage demanding a power consumption smaller than Light Load Mode (LLM), whereby the mission instruments are not ensured to work operational. When GOSAT is in Super Light Load Mode (S-LLM), the sensor will be kept in this All-off-Mode.	
Standby mode I		Keep the status necessary for conducting observations. Keep the temperature of sensor devices within the operational acceptance limits.	
Standby mode II		Keep the temperature of sensor devices within the acceptance limits.	
Light Load Mode (LLM)		A mode to keep the cloud-aerosol sensor in a state free from any defects, failures, or unrecoverable degradation in case GOSAT is placed in abnormal attitude and/or power supply is out of order; wherein only survival heaters and command reception circuits are kept on. The LLM is set effective when the primary power supply is switched on after the launch.	
Observation mode		Conduct observations	
Calibration mode	Lunar calibration	Calibrate sensitivity using the sunlight reflected from the moon at its highest average brightness while the spacecraft orient its +Z axis to the moon.	Done about once a year to calibrate some of the elements linearly arrayed whereon the calibrating light illuminates.
	Signal processing calibration	Calibrate the signal processor by applying nominal signal voltage before the analog signal processing unit.	about once a month
	Nighttime calibration	Calibrate offset levels by conducting night observations.	about once a month

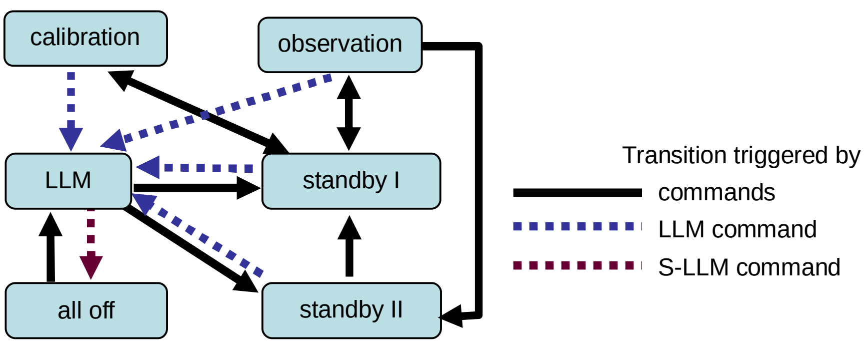


Fig. 3.2-2 TANSO-CAI operation mode transition diagram

3.2.3 On-orbit Operations

Fig. 3.2-3 shows the on-orbit operations of GOSAT, and the summary of each operation is described below ((1) to (5) in Fig. 3.2-3 respectively correspond to paragraphs (1) to (5) in the description of this section).

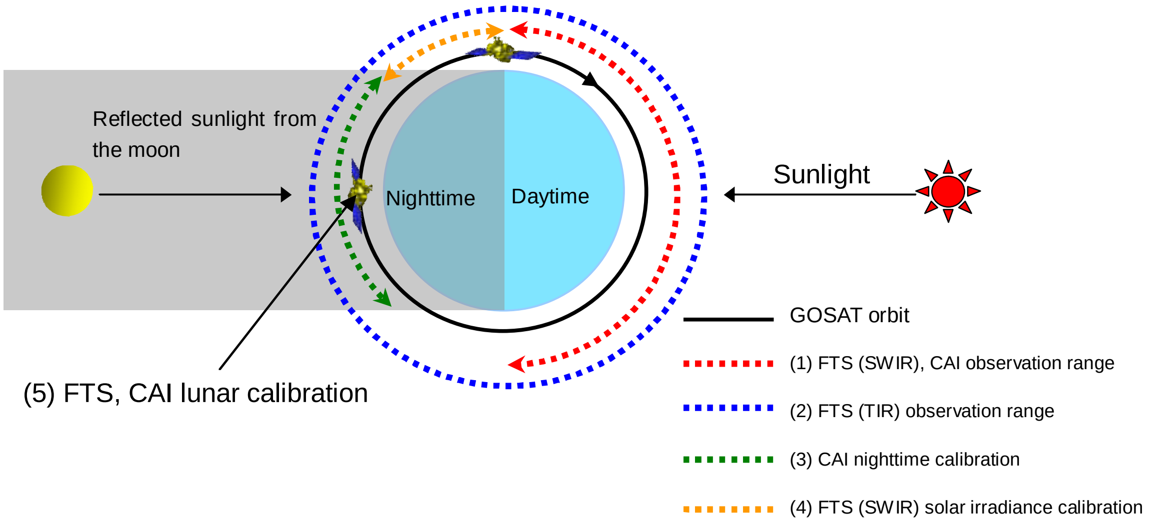


Fig. 3.2-3 On-orbit operations of GOSAT

(1) FTS SWIR and CAI observation

Since FTS SWIR and CAI observe the sunlight reflected from the ground surface, observation is performed only during the daytime. FTS SWIR is operated in the observation mode I or in the specific observation mode, while CAI is operated in the observation mode. FTS SWIR performs deep-space calibration at a position arbitrarily chosen on the orbit (performs it every revolution).

(2) FTS TIR observation

Since FTS TIR observes thermal radiation from the ground surface, the observation is performed during both the daytime and nighttime.
FTS TIR is operated in the observation mode I or in the specific observation mode.
FTS TIR performs blackbody calibration and deep-space calibration at a position arbitrarily chosen on the orbit (performs it every revolution).

(3) CAI nighttime calibration

CAI performs offset-level calibration using the data acquired in the nighttime when no incidental light may come into the optical system (performs approximately once a month).

(4) FTS SWIR solar irradiance calibration

Solar irradiance calibration is performed on FTS SWIR using the sunlight diffused by a diffuser plate as a calibration source when the satellite is in sunlight and the ground surface is in shadow (when passing above the north pole; performed every revolution).

(5) FTS and CAI lunar calibration

Lunar calibration for both FTS and CAI is carried out in the revolution in which the average luminance of the moon becomes its maximum (carried out about once a year).

3.2.3.1　Observation Pattern

In the routine observation, TANSO-FTS scans observation points in the CT direction with 1, 3, 5, 7, or 9 points to observe; this makes an grid-like pattern of observed points to calculate the interferogram about the atmosphere above them. On the other hand, TANSO-CAI captures images of the ground surface. Fig. 3.2-4 shows an schematic diagram of GOSAT observation, while Fig. 3.2-5 shows a CT scanning pattern of FTS.

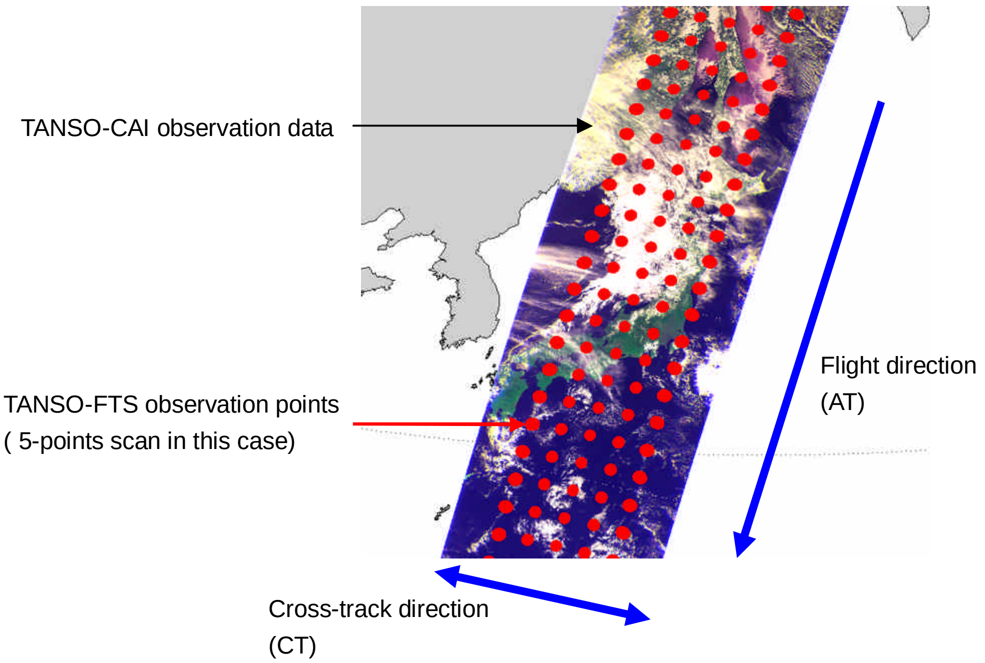


Fig. 3.2-4　Schematic diagram of GOSAT observation
(FTS is in 5-points scan mode)

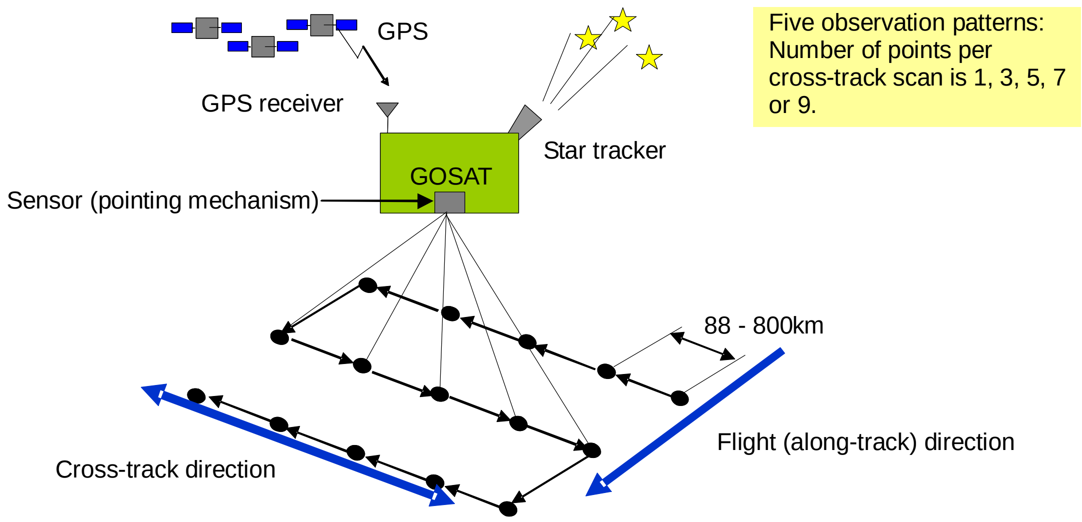


Fig. 3.2-5 CT scanning pattern of FTS

Observation time, distances between the observation points, and the like differ depending on the number of CT scanned points. Table 3.2-3 indicates the pattern of an observation cycle for each scanned point. Table 3.2-4 shows the distance between the observation points in the CT direction and the AT direction for each observation pattern.

Table 3.2-3 CT scanning and observation cycle

Number of CT scanned points	Observation duration at a time per point (sec)	Number.of repetitions on the same point
1-point observation	4.0	3
3-point observation	4.0	3
5-point observation	4.0	1
7-point observation	2.0	1
9-point observation	1.1	1

- ✓ It is permitted to lock the pointing mechanism immediately before the start time of a specified observation so as to adjust the observation timing.
- ✓ Number of repetitions on the same point: observation is made for the same point multiple times to sum up the observed data to improve the accuracy of SNR.

Table 3.2-4 Time and location distances between observation points in AT and CT directions

Number of CT scanned points	Horizontal distance at latitude 30 deg (km)	Vertical distance at latitude 30 deg (km)	Observation time per observation point (sec)	CT settling time (sec)	AT settling time (sec)	AT interval time (sec)	AT angular range (deg(+/-))
1-point observation	788.8	90.3	12.8	N/A	0.4	13.2	3.7
3-point observation	262.9	283.1	13.2	0.6	0.6	41.4	12.1
5-point observation	157.8	152.2	4.0	0.45	0.45	22.2	6.5
7-point observation	112.7	114.9	2.0	0.4	0.4	16.8	4.9
9-point observation	87.6	86.2	1.1	0.4	0.4	12.6	3.7

- ✓ Observation time per observation point: in the 1-point and 3-point observation modes, it includes twice of the turnaround time (CT settling time = AT settling time) since interferogram is superimposed three times.

- ✓ AT interval time = observation time per observation point × Number of CT observation points + CT settling time × (Number of CT observation points - 1) + AT settling time = (observation time per observation point + turnaround time) × Number of CT observation points

The pointing mechanism performs Image Motion Compensation (IMC) about the AT-axis during a scan in the CT direction, thereafter returns the mirror about the AT-axis to do a subsequent scan after the primary scan.

Fig. 3.2-6 illustrates the operation of the pointing mechanism and the mirror angles permitted about the two axes.

The pointing mechanism carries out the scan operation on both the AT-axis and CT-axis in synchronization with turnaround signals transmitted from the interferometer controller (transmitted at the timing when the FTS scan mirror returns back; see Fig. 3.2-7).

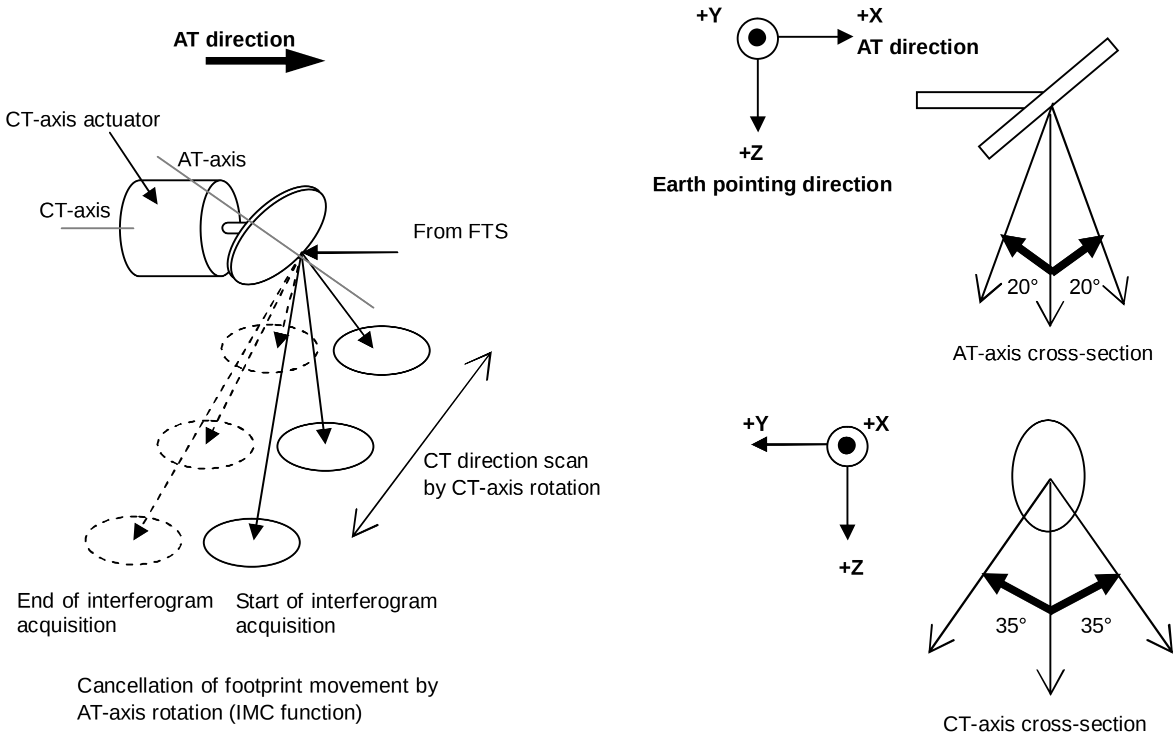


Fig. 3.2-6 Pointing mechanism movement and mirror angles permitted about AT-axis and CT-axis

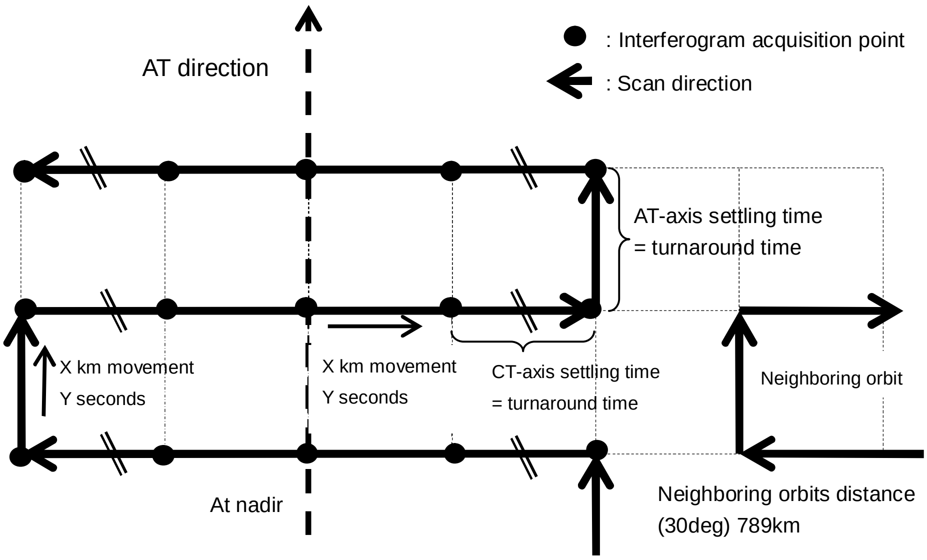


Fig. 3.2-7 Synchronization of turnaround time with the CT-axis and AT-axis settling times

3.2.3.2 Constraints

(1) Synchronization between the pointing mechanism and Fourier interferometer

As the pointing mechanism performs the scan operation synchronized to the turnaround signals transmitted from the Fourier interferometer, the following periods of time must be kept the same.

- The time needed for the scan mirror of the Fourier interferometer to return back (= turnaround time)
- CT-axis settling time of the pointing mechanism
- AT-axis settling time of the pointing mechanism

(2) Constraints of the Fourier interferometer

- Adjustable range of turnaround time: 300ms to 650ms

(3) Settling time constraints of the pointing mechanism

- 1, 7, and 9-point CT observations: 400msec
- 5-point CT observation: 450msec
- 3-point CT observation: 600msec

The turnaround time can be set in a range of 300 to 650msec (nominal 400msec). An example of a driving sequence in the 5-point observation mode is shown in Fig. 3.2-8, in which all of the turnaround times take the smallest value (300ms).

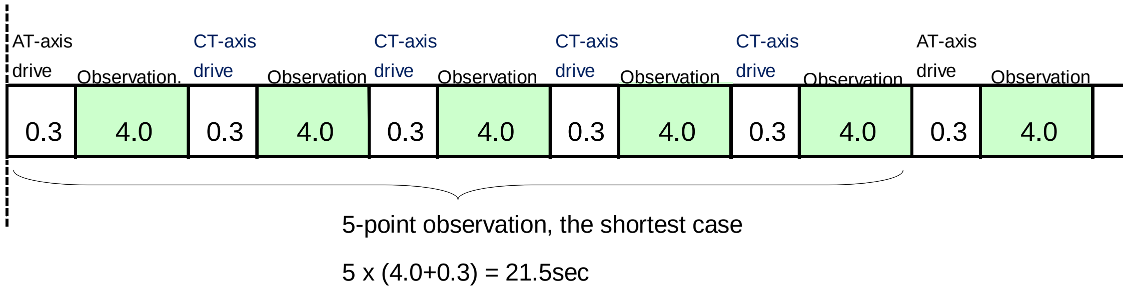


Fig. 3.2-8 Example of a driving sequence in the 5-point observation mode, with a 300msec turnaround time

3.2.4 Summary of Nominal Operation

3.2.4.1 Routine Observation with no Sunglint Observation

(1) Operation overview

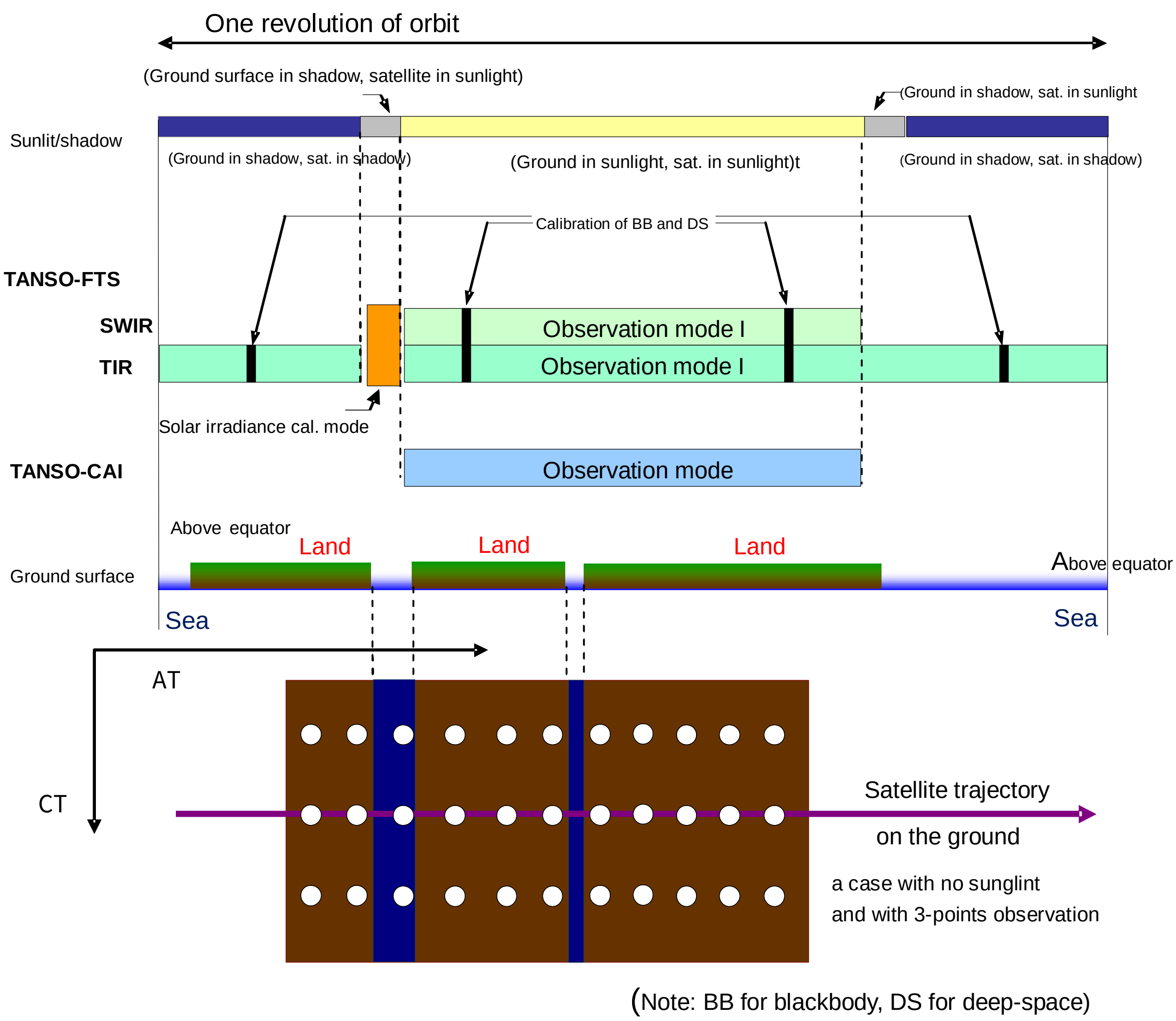
The routine observation with no sunglint is a pattern of operation frequently applied to GOSAT; its summary is described below. The outline of the sunglint observation is mentioned in section 3.2.4.2.

- FTS and CAI carry out the observation in the observation mode I and the observation mode, respectively.
- SWIR of FTS and CAI observe the ground surface in a sunlit condition.
- Start and end times for the daytime observation by SWIR of FTS and CAI are specified by stored commands (command including a time as a parameter to be triggered by the clock).
- TIR of FTS observes both sunlit and shadow regions all the time.
- For a routine observation of the FTS observation mode I, there are provided a total of five modes each corresponding to each of the numbers of scanning points in the CT direction, i.e., 1, 3, 5, 7, and 9.
- FTS receives the ascending node passing time from the satellite so as to adjust the clock time (for adjusting FTS scan cycles).
- The same observation points, with the same number of CT scan points (1, 3, 5, 7, and 9) and accompanied observation mode, are observed repeatedly every three-day recurrent cycle (geolocational allowance: 4 km).
- At the initial stage of nominal operation, FTS started its observation with a scanning pattern of five points in the CT direction (scan time: 4.0 seconds per point) resulting in a grid-like pattern of observed points mapped on the ground; on June 26, 2009 however, the scanning pattern was changed to a W-shaped one.

- On August 2, 2010, the number of scanning points in the CT direction was changed from 5 to 3 (scan time: 13.2 seconds per point); since then, the scan operation has been carried out with the three scanning points in the CT direction[5].

(2) Example of operation pattern

CAI acquires images of the ground when the surface is sunlit. An example of routine observation (3-point observation) without sunglint observation is illustrated in Fig. 3.2-9, wherein FTS works in the observation mode I with three scanning points in the CT direction.



(Note: BB for blackbody, DS for deep-space)

Fig. 3.2-9 Example of routine observation (3 points) with no sunglint observation

[5] The standard location of the points meshed by 5 and 3 scans are found on GUIG website by tracing "Products and Services" → "Path calendar". About GUIG (GOSAT data distribution website) further explanation is given in chapter 7.

3.2.4.2 Routine Observation with Sunglint Observation

(1) Operation summary

FTS conducts a sunglint observation above the ocean as a specific observation mode of the FTS. The observation mode applied to sunglint observation is similar to the mode for specific point observation later explained (see section 3.2.4.3 and 3.2.4.4). As seawater absorbs sunlight, it is usually difficult to observe reflection of the sunlight above the oceanic areas. However, at a sunglint point wherefrom the sunlight is reflected towards the spacecraft just like it is reflected by a mirror, sufficient amount of light is reflected to allow an observation.

The area for sunlight observation is set for each season and the observation is conducted at the places located on middle to low latitude above the ocean. Observation time and angles of AT and CT are specified by the commands sent from the ground so that the observations of sunglint points are performed over a strip-shaped region.

(2) Example of operation pattern

Fig. 3.2-10 illustrates an example of routine observation including a sunglint observation in the sunlit area. FTS switches from the observation mode I (5-point observation) to the specific observation mode at the start of a sunglint to observe, performs the sunglint observation, and returns back to the observation mode I.

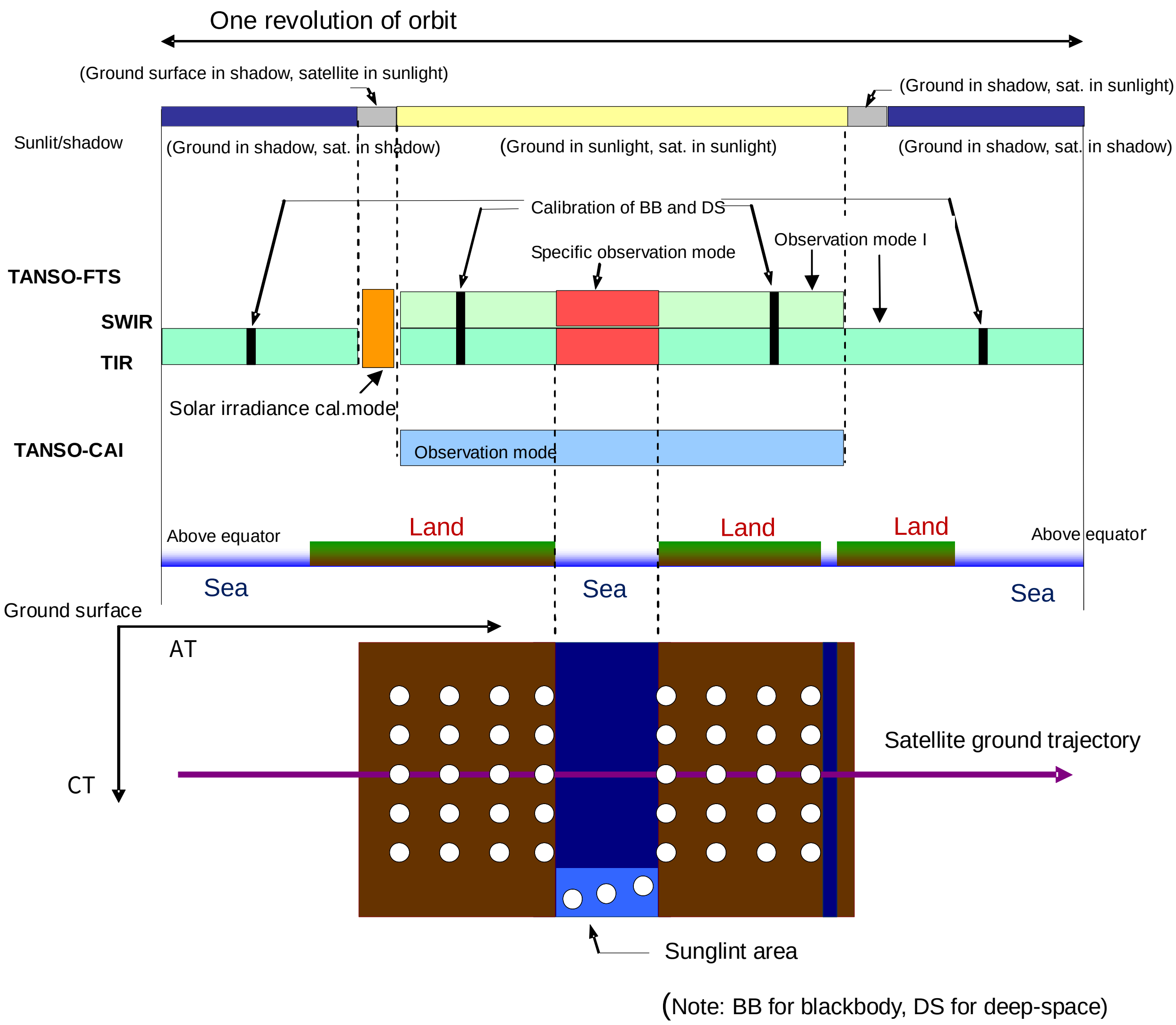


Fig. 3.2-10 Example of routine observation with a sunglint observation

Figs. 3.2-11 and 3.2-12 schematically illustrate the regions on the satellite paths over which sunglint observation is performed (sunglint operation region) at the winter solstice and summer solstice, respectively (purple colored bold-lines show the sunglint region). A numeral written on a path indicates the number of sunglint observations conducted for each path taking a series of observations on consecutive points as a unit.

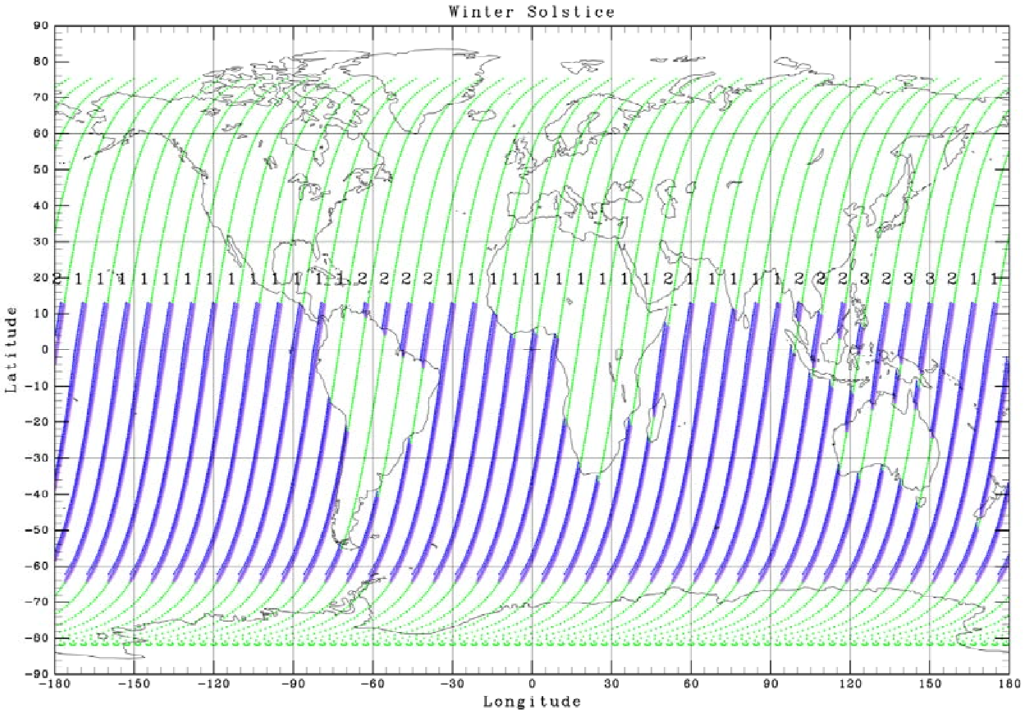


Fig. 3.2-11 Example of sunglint operation span (winter solstice)

A numeral on each path is the number of consecutive observation points in the same path on a land area.

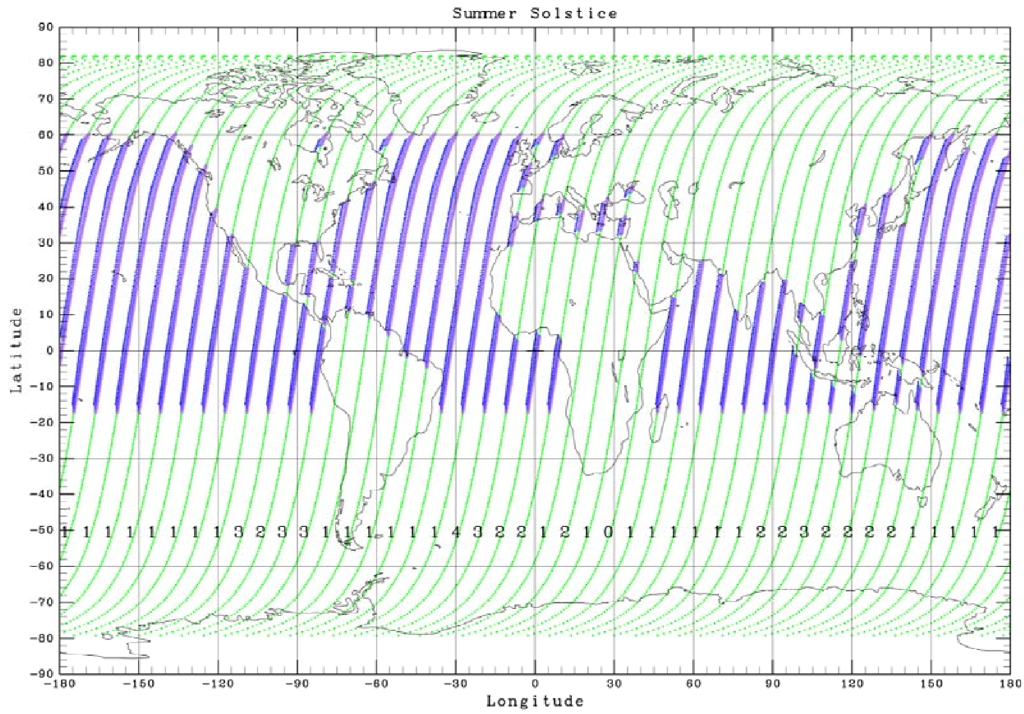


Fig. 3.2-12 Example of sunglint operation span (summer solstice)

A numeral on each path is the number of consecutive observation points in the same path on a land area.

3.2.4.3 Specific Point (1-point) Observation

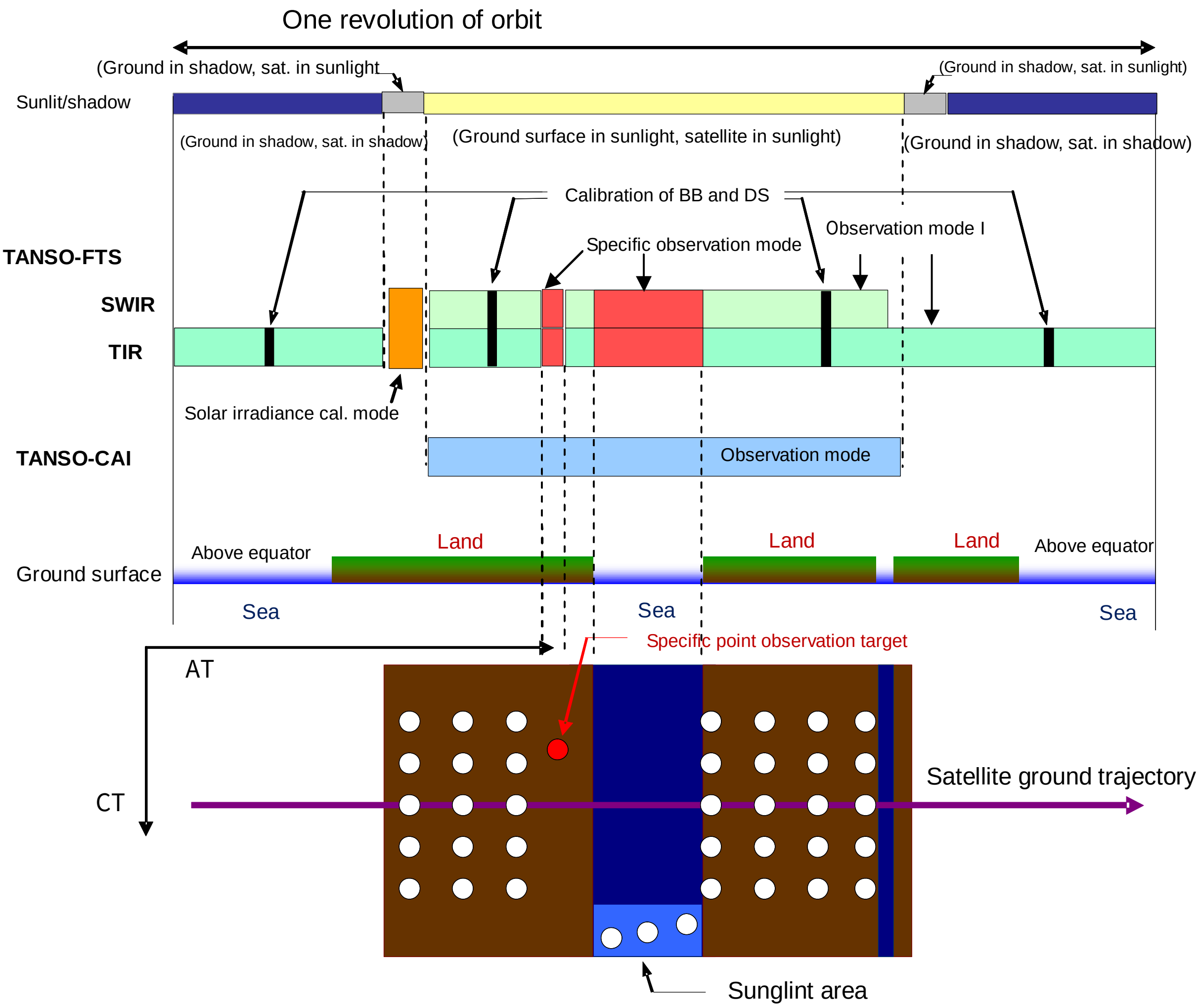
(1) Operation summary

For observing a specific and relatively narrow region such as a calibration and/or validation site, the specific observation mode is taken to carry out FTS specific point (1-point) observation. The observation mode applied to this observation is the same as the one applied to sunglint observation (see section 3.2.4.2) and/or specific points (consecutive) observation (see section 3.2.4.4). The observation time and angles of AT and CT are specified by the commands sent from the ground.

If the time for a specific point observation and the time for a blackbody / deep-space calibration (see section 3.2.6) overlap each other, the blackbody / deep-space calibration is given priority and executed. Accordingly, in order to carry out a specific point (1-point) observation, some of the times for blackbody / deep-space calibration must be changed beforehand.

(2) Example of operation pattern

Fig. 3.2-13 illustrates an example of observation including a specific point (1-point) observation on the sunlit area. FTS switches from the observation mode I (5-point observation) to the specific observation mode at the point to observe, carries out the specific point observation, and returns back to the observation mode I.



(Note: BB for blackbody, DS for deep-space)

Fig. 3.2-13 Example of observation with a specific point (1-point) observation

3.2.4.4 Specific Point (Consecutive) Observation

(1) Operation summary

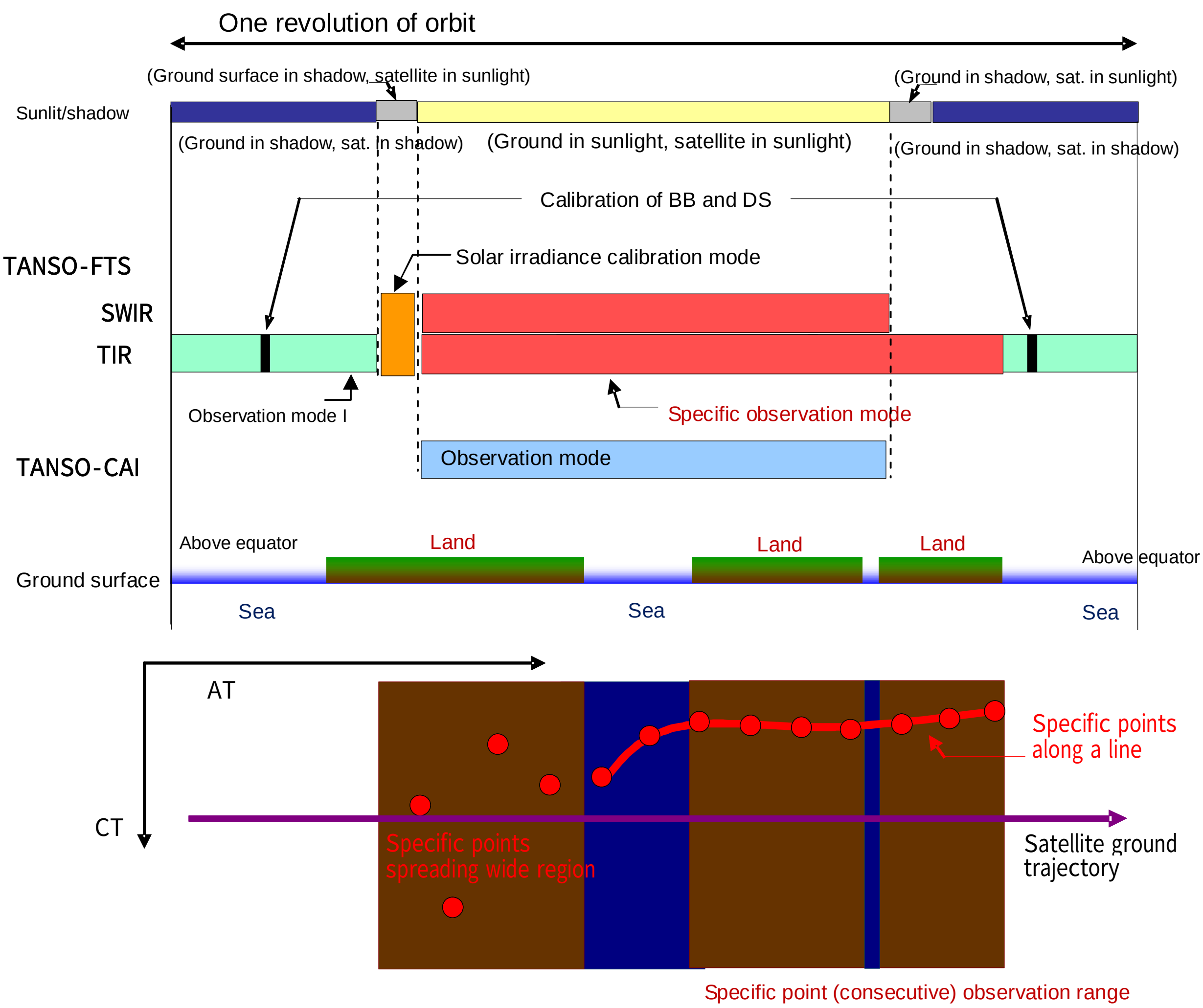
For observing a specific points consecutively, a specific point (consecutive) observation is carried out as a FTS specific observation mode. The specific point (consecutive) observation enables the consecutive observation of points spreading wide region or the one along a line. The observation mode applied to this observation is the same as the one applied to sunglint observation (see section 3.2.4.2) and/or specific point (1-point) observation (see section 3.2.4.3). The observation time and angles of AT and CT are specified by the commands sent from the ground.

If the time for a specific points observation and the time for a blackbody / deep-space calibration (see section 3.2.6) overlap each other, the blackbody /

deep-space calibration is given priority and executed. Accordingly, in order to carry out the specific point (consecutive) observation some of the times for blackbody / deep-space calibration must be changed beforehand.

(2) Example of operation pattern

Fig. 3.2-14 illustrates an example of a specific points (consecutive) observation on the sunlit area. FTS switches from the observation mode I to the specific observation mode at the start of the region to observe, carries out the specific point observation, and returns back to the observation mode I.



(Note: BB for blackbody, DS for deep-space)

Fig. 3.2-14 Example of specific point (consecutive) observation

3.2.5 Operation of Lunar Calibration

GOSAT calibrates the sensitivity of FTS and CAI using the sunlight reflected from the moon surface as a calibration source; this type of calibration is performed about once a year. The calibration source is the amount of light reflected from the whole surface of the moon and integrated over a time.

Through this calibration CAI can calibrate the sensitivity for a limited number of elements arrayed in line because only a portion of the arrayed elements is hit upon by the calibration light from the moon. The remaining elements are calibrated using the light reflected from the ground as the surface of a desert; the sensitivity of such elements is calibrated by relatively comparing the behavior of the elements with the ones already calibrated. In case an element placed at the central portion of CAI had a failure, an offset bias is given to the pointing direction of the satellite so as to avoid using the element in failure.

The lunar calibration is performed in a revolution when the sun, earth, and satellite make an angle of approximately 180 degrees, and at the time when the average luminance of the moon reaches its maximum as viewed from GOSAT. During the revolution in which the lunar calibration is performed, the satellite is controlled to keep the earth out of sight in order not to let the earth's surface and the atmosphere below 100km come into the view field of FTS (± 35deg in the CT direction and ± 20deg in the AT direction measured from the GOSAT's nadir).

For the lunar calibration of FTS, GOSAT orients its +Z-axis (earth pointing direction) toward the center of the moon for more than two minutes, during which the whole moon come into the view field of FTS. After that, in order to capture images for CAI, GOSAT rotates itself at a uniform speed of 0.04 ± 0.01deg/sec about the Y-axis with a range of ±1.3deg to cover the whole surface of the moon; this rotational motion is repeated twice consecutively (4 scans).

(As for the definition of axes of GOSAT, see Fig. 2.1-1.)

3.2.6 Operation of Blackbody / Deep-Space Calibration

In the observation mode I or the specific observation mode of FTS, blackbody and deep-space calibration operations are performed for every revolution at places arbitrarily specified by the command transmitted from the earth (the specification is made by the time to elapse since the satellite passes the ascending node; a maximum of 16 times of calibrations may be specified). The blackbody calibration is performed on FTS TIR, while the deep-space calibration is performed on both FTS SWIR and TIR. Figs. 3.2-9, 3.2-10, 3.2-13, and 3.2-14 illustrate the timing the blackbody and deep-space calibrations are carried out. The calibration timing may be changed to meet the needs; if no changes are made, calibrations are performed at the same timing as in the preceding revolution.

The blackbody and deep-space observations for calibration are carried out in the same observation time (1.1, 2, or 4 seconds; see Table 3.2-3) as the observations conventionally performed. Both the blackbody and deep-space calibrations need observations of four points; in addition, a transition between a observation and a calibration takes the time almost the same as the time to observe one point; however, data rate does not change because the detectors keep accepting the data even in the transitions.

3.2.7 Operation of Solar Irradiance Calibration

In order to calibrate the sensitivity of FTS SWIR, GOSAT switches to the solar irradiance calibration mode and performs the calibration for about two minutes, once per revolution, immediately before its nadir comes into the sunlit area on the surface of the ground (at the time when the sunlight hits upon the solar irradiance calibration plate). The time of calibration is specified by the command for each revolution; no calibration is carried out if no commands are given.

Figs. 3.2-9, 3.2-10, 3.2-13, and 3.2-14 illustrate the timing the blackbody and deep-space calibrations are carried out.

3.3 Setting of Sunglint Observation Region

In order to carry out the sunglint observations, the values defining the sunglint regions (see of Appendix A2 (3)) and the sunglint operation span (see Appendix A2 (4)) must be specified before planning the sunglint observation. These values are calculated for every quarter of a year, or every season.

GOSAT observations are planned for every month based on observation requests while the requests of sunglint observation are basically issued as an internal observation request. If any change is required for the plan, the whole plan of the month is reconfigured again.

3.4 Setting of Observation Gain

A gain is a factor to amplify an input signal to a voltage appropriate for signal processing; it must be given by a command depending on the brightness (amount of light input) of the target to be observed. Both FTS and CAI of GOSAT can set the gain in three levels, L (Low), M (Middle), or H (High).

Observation gains for each of FTS and CAI are described below.

(1) Setting of TANSO-FTS gain

Three levels (Low/Middle/High) of gain setting are available for each polarization component (P-polarization and S-polarization) in the case of SWIR (Bands 1, 2, and 3). On the other hand, the gain for TIR (Band 4) is a fixed value.

Principal gain settings for FTS are shown below.

- Routine observation, specific point observation: Gain H
  Note that the gain M is chosen, if necessary, to observe desert areas located in low latitude with a high ground surface reflectance.
- Sunglint observation: Gain H
  Note that the gain M is chosen if necessary.
- Solar irradiance calibration: Gain M (fixed)
- The gain Low is not used in principle.

In the following types of observation, the gain may be changed depending on paths and an argument of latitude (see appendix A2 (6)).

- When the satellite passes through the predetermined range of argument of latitude.
- When a sunglint observation is performed.
- When a specific point observation is performed.

(2) Setting of TANSO-CAI gain

As of December, 2010, the gain for CAI is controlled by adjusting the duration of time, integration is carried out; while three levels (Low/Middle/High) of gain value are applicable to CAI.

The integration time duration will be defined depending on paths and an argument of latitude. The values of time duration thus assigned are kept as a static parameter and may be altered as required.

Chapter 4　GOSAT Ground System

4.1　Overview of GOSAT Ground System

The GOSAT ground system consists of the JAXA and NIES systems. The JAXA system performs operations such as satellite control, data acquisition and primary data processing, whereas the NIES system performs operations such as higher level data processing and products distribution. In addition, a data acquisition station located at high latitude (SvalSat / Norway) is utilized in order to increase data acquisition opportunities.

The overall configuration of GOSAT ground system is illustrated in Fig. 4.1-1.

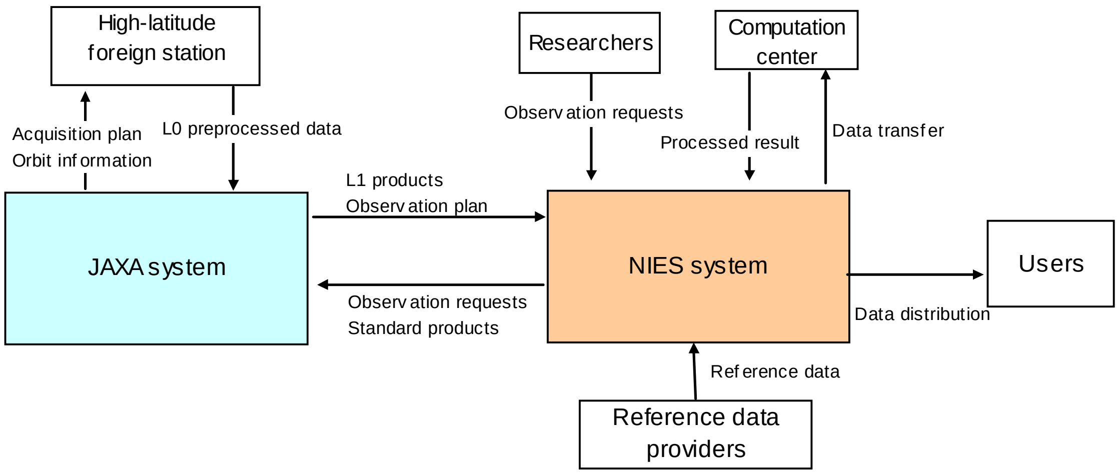


Fig. 4.1-1　Overall configuration of GOSAT ground system

4.2　JAXA System

The configuration of JAXA system is illustrated in Fig. 4.2-1, and general functions of each component in the JAXA system are described below.

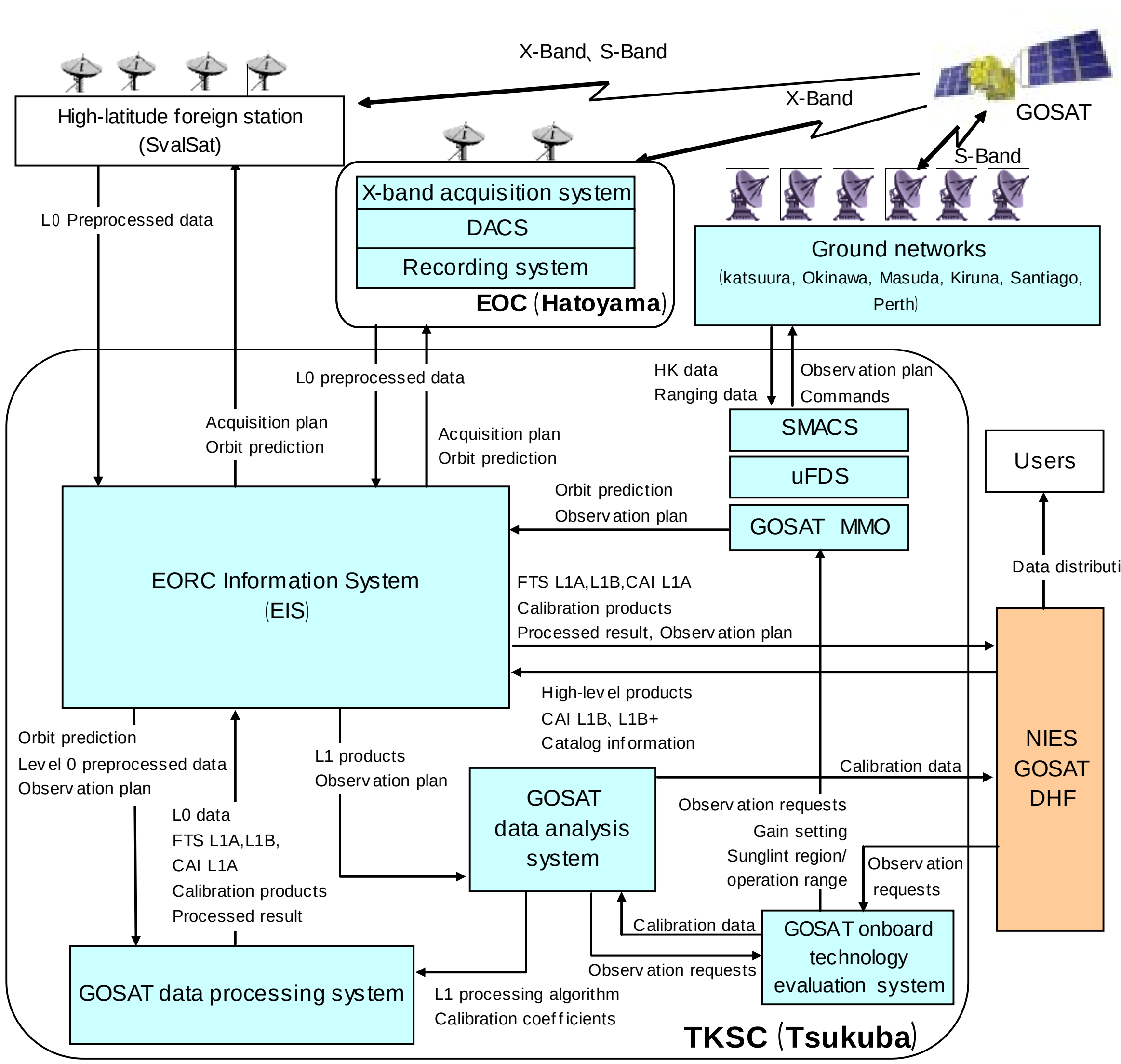


Fig. 4.2-1 Overall Configuration of JAXA System

(1) X-band acquisition system

- The X-band acquisition system tracks GOSAT to capture X-band mission data (via DT) from the satellite, amplifies the signal level of the acquired data to a predetermined level, and demodulates the signal data to transmit to the recording system.
- This system is composed by adding a demodulator for GOSAT and a modulator for test signal generation to the acquisition system for Advanced Earth Observing Satellite "Midori" (ADEOS) and Marine Observation Satellite-1 "Momo-1" (MOS-1) placed in the Earth Observation Center (may called hereafter EOC). GOSAT shares the X-band acquisition system with Advanced Land Observing Satellite "Daichi" (hereafter called ALOS) which is in operation as of December 2010.

- The X-band acquisition system is installed in the EOC.

(2) Recording system

- The recording system receives the demodulated signals outputted from the X-band acquisition system, carries out packet synchronization processing in accordance with the CCSDS (Consultative Committee for Space Data System) recommendation, and creates the APID sorted data (called hereafter Level 0 preprocessed data) to record them in a hard disk. The recording system also records the demodulated signals directly after digital conversion (hereafter called RAW data).
- The recorded GOSAT Level 0 preprocessed data are transmitted to the GOSAT Data Processing System via the EORC Information System (may called hereafter EIS).
- The recording system is installed in the EOC.

(3) Foreign stations on a high-latitude (SvalSat / Norway)

- In order to acquire the global observation data, the Svalbard Satellite station (hereafter called SvalSat), operated by Kongsberg Satellite Services (hereafter called KSAT, Norway), is utilized as an overseas data acquisition station located at high latitude.
- When mission data are downlinked from a satellite on a sun-synchronous orbit, only a limited number of satellite passes are visible from the stations in Japan because Japan is located at middle latitude to cover a small portion of satellite passes. On the other hand, all of the satellite passes are visible to the stations in a high-latitude country; accordingly, a number of satellite passes far greater than in Japan are available for data acquisition.
- SvalSat acquires X-band mission data from the satellite, creates Level 0 preprocessed data, and records the created data together with RAW data in a hard disk.
- The recorded GOSAT Level 0 preprocessed data are transmitted to the GOSAT Data Processing System via EIS.
- SvalSat is also utilized as a backup station for S-band operations.

(4) EOC Data Acquisition Control System

- An operational conflict between ALOS and GOSAT takes place because data acquisition operations for these satellites are performed simultaneously at EOC. The EOC Data Acquisition Control System must resolve such conflict.

- The system examines and resolves the conflict to produce acquisition plans for each of the satellites and manages the operation schedules of the X-band acquisition system, the recording system, etc. The system distributes the operation plans as well.
- The EOC Data Acquisition Control System is installed in the EOC.

(5) GOSAT Data Processing System

- The GOSAT Data Processing System performs Level 0 processing of GOSAT mission data, performs Level 1 processing of TANSO-FTS and TANSO-CAI mission data, and creates calibration data.
  The system is installed in the Tsukuba Space Center (may called hereafter TKSC).

(6) GOSAT Onboard Technology Evaluation System

- The GOSAT Onboard Technology Evaluation System accepts observation requests of TANSO-FTS from NIES; requests from the Science Team are also included.
- The system puts together the observation requests from NIES and observation requests from the GOSAT operation team of JAXA to coordinate them, and transmits the coordinated result to the GOSAT Mission Management and Operation system.
- The GOSAT Onboard Technology Evaluation System is installed in the TKSC.

(7) GOSAT Mission Management and Operation system (GOSAT MMO)

- This system schedules and manages observation plans and downlink plans of TANSO-FTS and TANSO-CAI.
- The system accepts observation requests from NIES via the GOSAT Onboard Technology Evaluation System to reflect them in the GOSAT observation plan, which is provided to NIES.
- GOSAT MMO is installed in the TKSC.

(8) SMACS (Spacecraft MAnagement Control System) and uFDS (unified Flight Dynamics System)

- SMACS and uFDS generate operation commands for the satellite based on the GOSAT observation plan made by GOSAT MMO, and transmit them to the satellite through the domestic and overseas tracking control stations (Ground Networks).

- SMACS and uFDS acquire House Keeping and ranging data from the satellite to monitor the conditions of the satellite and sensors in orbit, and also determine the orbit to create orbit information such as orbit data predictive.
- SMACS and uFDS are installed in the TKSC.

(9) EORC Information System (EIS)

- This system manages input / output operations from / to external systems such as the GOSAT Data Processing System and GOSAT MMO.
- EIS archives and manages L0 data of TANSO-FTS and TANSO-CAI as master data. Further, EIS archives and manages TANSO-FTS Level 1A and 1B products, TANSO-CAI Level 1A products, and their calibration products, all of them being processed by JAXA.
- Furthermore, EIS archives and manages TANSO-CAI Level 1B, 1B+, and higher level products; and TANSO-FTS higher level products. The products mentioned here are processed by NIES and provided to JAXA.
- EIS is installed in the TKSC.

(10) GOSAT Data Analysis System

- In the GOSAT Data Analysis System, research activities on the use of GOSAT data are carried out making use of such data and products as follows, i.e. Level 1 products and Level 1 calibration products created in the GOSAT Data Processing System, and TIR input / output data set and Grid Point Value (GPV) data provided by NIES; the creation of GOSAT research products is also included in the activity.
- The system obtains the calibration data, not contained in Level 1 calibration products created in the GOSAT Data Processing System, from the GOSAT operations team of JAXA and provides them to NIES.
- The GOSAT Data Analysis System is installed in the TKSC.

(11) Ground Networks

- The Ground Networks help exchanging data among JAXA ground stations for their tracking and controlling of the satellite.

4.3 NIES System

In the NIES System, the GOSAT Data Handling Facility (hereafter called NIES GOSAT DHF) deals with GOSAT-related data (excluding some part of processing). Fig. 4.3-1 illustrates the overall configuration of NIES GOSAT DHF. General functions of NIES GOSAT DHF will be described below.

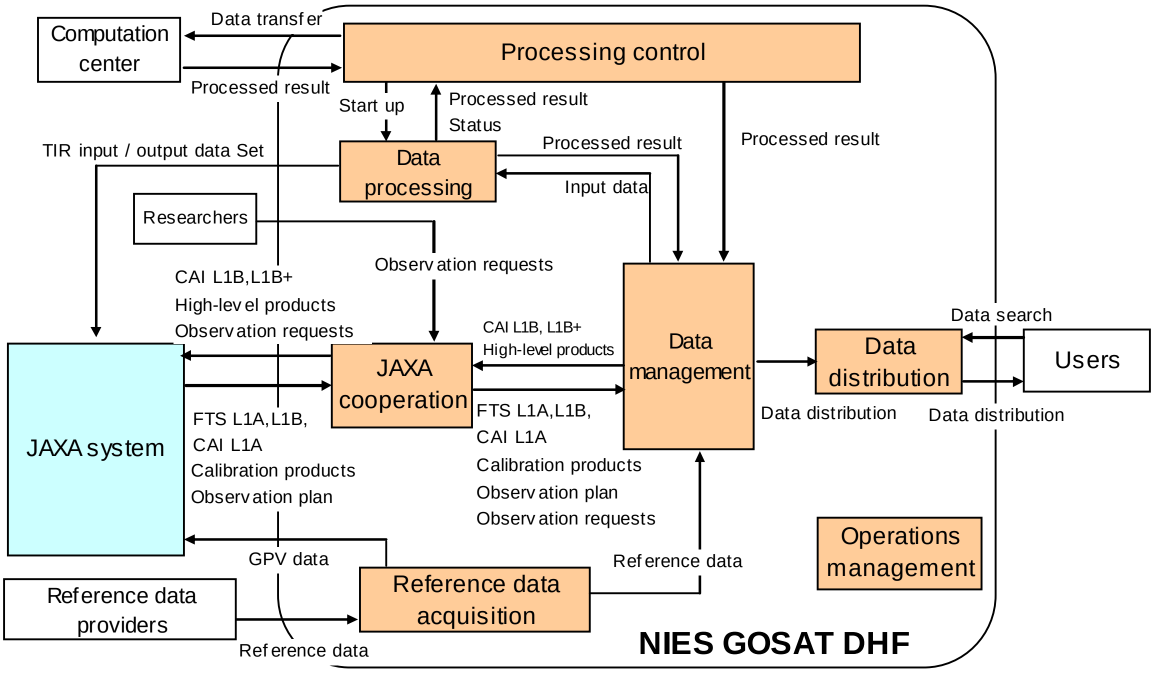


Fig. 4.3-1 Overall configuration of NIES GOSAT DHF

(1) JAXA cooperative subsystem

- The JAXA cooperative subsystem puts together GOSAT observation requests from the MOE, NIES, the Science Team, Research Announcement Investigators (RAs), and so on; coordinates these requests and presents the coordinated result to JAXA in a predetermined form of observation request.
- Compares the observation request thus presented with a corresponding observation plan made by and sent from JAXA.
- The subsystem obtains the following products from JAXA: TANSO-FTS Level 1A, Level 1B products; TANSO-CAI Level 1A products; TANSO-FTS Level 1A, 1B calibration products; and TANSO-CAI Level 1A calibration products. In addition, it obtains the calibration data that are not contained in Level 1 calibration products.
- Among the TANSO-CAI Level 1B, 1B+, and higher level products that are processed by NIES, the products that are classified as a standard product of stage C (as for the stages, see section 7.2.4) are provided to JAXA with their catalogue.
- The subsystem provides JAXA with dataset files storing the input/output data of the TANSO-FTS TIR gas concentration calculation processing, and GPV data which have been acquired as reference data.

(2) Reference data acquisition subsystem

- Acquires reference data necessary for the GOSAT higher level processing from the organizations that supply the reference data.
- Acquires validation data necessary for the validation of GOSAT higher level products from the organizations that supply the validation data.

(3) Processing control subsystem

- Controls operations of data processing such as starting-up, terminating, and scheduling of the process.
- Manages conditions for data processing.
- The subsystem also controls the data processing carried out in computer centers other than NIES GOSAT DHF.

(4) Data processing subsystem

- The subsystem inputs TANSO-FTS Level 1A, 1B products, TANSO-CAI Level 1A products, Level 1 calibration products of TANSO-FTS and TANSO-CAI, and reference data; and performs the following higher level processing to output the results.
  - TANSO-CAI Level 1B, 1B+ processing
  - TANSO-CAI Level 2 processing
  - TANSO-FTS SWIR Level 2 processing
  - TANSO-FTS TIR Level 2 processing
- Further, the subsystem inputs TANSO-FTS Level 2 products and reference data, and performs the following higher level processing to output the results.
  - Level 3 processing
  - Level 4A processing
  - Level 4B processing
- Part of the data processing is done in the computer centers other than NIES GOSAT DHF.

(5) Data management subsystem

- The subsystem archives and administers the products and data, which include those provided by JAXA, i.e. TANSO-FTS Level 1A, Level 1B, TANSO-CAI Level 1A, their calibration products, and those processed by NIES; i.e. TANSO-CAI Level 1B, 1B+ and higher level products, and reference data and validation data necessary for data processing.

(6) Data distribution subsystem

- Distributes the created higher level products to users.

(7) Operations management subsystem

- Monitors the operation status of computer systems installed in NIES GOSAT DHF.

Chapter 5 GOSAT Ground System Operations

5.1 GOSAT Ground System Operations Outline

NIES collects observation requests at NIES GOSAT DHF and sends them to JAXA. JAXA makes observation and operation plans, based on the observation requests sent from NIES and the observation requests issued by the GOSAT operations team of JAXA, and transmits them in the form of commands to the satellite.
GOSAT carries out the observation in accordance with the observation plan, and sends the observed data down to EOC and/or SvalSat as specified in the operation plan; the data downlink is conducted every two passes approximately,
The ground station that has acquired the data performs, after demodulating the signals, packet synchronization and APID sorting. Thereafter, the processing for the skipped data is executed by referring to the header portions of the acquired data. Then Level 0 data are created, and level 1 processing is also performed according to the scene definition for the Level 1 products. The Level 1 products thus generated are sent to NIES GOSAT DHF for higher level processing, and become ready for distribution to users.

5.2 GOSAT Data Acquisition and Transfer

This section explains briefly how the GOSAT data are acquired and transferred. See chapter 4 for overall configuration of the GOSAT systems.

- The X-band acquisition and recording systems installed in EOC of JAXA acquire two to four passes of downlink data from GOSAT every day.
- SvalSat in Norway acquires about six passes of downlink data from GOSAT every day. Svalsat is run by KSAT in Norway.
- Each of the stations that has acquired the observation data applies digital conversion to the demodulated signals and performs packet synchronization processing and APID sorting so as to generate Level 0 preprocessed data, which are transmitted to the GOSAT Data Processing System via EIS.
- In addition, the RAW data, which are obtained by applying digital conversion to the demodulated signals, and the Level 0 preprocessed data are both archived for a certain period of time in each station for use in cases such as re-transmission, re-processing, and the like.
- The GOSAT Data Processing System at JAXA process the Level 0 preprocessed data to produce Level 0 data (the processing is done for skipped data by referring to primary and secondary headers, etc.). The created Level 0 data (TANSO-FTS,

TANSO-CAI, TEDA, CAM, MDP, HK (House Keeping), etc.) are archived in EIS together with the processing result. The Level 0 data registered at EIS are copied to and archived also in EOC for disaster backup.

5.3 GOSAT Data Processing

Data processing operations for GOSAT standard products are described below.

5.3.1 Level 1 Processing

5.3.1.1 TANSO-FTS 1B Processing

- The GOSAT Data Processing System, installed in TKSC of JAXA, inputs Level 1A products to create Level 1B products. The system also creates calibration products of TANSO-FTS Level 1B. Upon completion of the Level 1 processing for a scene, the products are transmitted online one after another to NIES GOSAT DHF via EIS.
- Processing result files are made as soon as the corresponding Level 1 products are generated, and sent also to NIES GOSAT DHF via EIS.
- The products thus created are archived and managed at both EIS and NIES GOSAT DHF.

5.3.1.2 TANSO-CAI Level 1B, 1B+ Processing

- NIES GOSAT DHF creates Level 1B and 1B+ products from TANSO-CAI Level 1A products JAXA provided.
- The created products are archived in a database of NIES GOSAT DHF. In addition, a data distribution server provides, via Internet, services for search and distribution of the archived data.

5.3.2 Higher Level Processing

- NIES GOSAT DHF collects, through the routine operation, such reference data as meteorological data which are necessary for higher level processing; these data are collected from various organizations such as Japan Meteorological Agency, European Center for Medium-Range Weather Forecasts (ECMWF), National Oceanic and Atmospheric Administration (NOAA), and so on. NIES GOSAT DHF also manages the validation data necessary for validation of the products.
- NIES GOSAT DHF creates higher level products using some of the standard

products and reference data; the standard product will be FTS Level 1B acquired from JAXA or CAI Level 1B and 1B+ created by NIES. For this processing, in addition to the facilities in NIES GOSAT DHF, computer centers inside and outside of NIES (including a supercomputer of NIES, and Information Technology Center of the University of Tokyo) are used for such processes as retrieval processing which requires a lot of computation power.

- The created products are archived in a database of NIES GOSAT DHF. In addition, a data distribution server provides, via Internet, services for search and distribution of the archived data.

Chapter 6　GOSAT Products

6.1　Product Unit

A GOSAT product unit is defined depending on sensors and processing levels. Typical product units are explained below.

(1) FTS scene

FTS scene of Level 1 product is defined to have a span covered by the observation performed in a time 1/60 of the one-revolution period; the start of the first scene corresponds to the ascending node passing time. A scene of FTS data is the unit to archive FTS Level 1 products. Fig. 6.1-1 shows schematically how the FTS scenes are defined.

If the time to end a scene comes before completing an interferogram, the interferogram shall be included in the scene the observation was started.

An FTS Level 1 product is created for each respective scenes; no overlaps between two adjacent scenes, accordingly, no data are shared by different product units. If a change in sensor's observation mode (daytime observation, nighttime observation, sunglint observation, and specific point observation) takes place within a scene, the scene is divided at the place the mode changes. The divided scenes are named as sub-scene, and a product is composed of each of the sub-scenes. However, if sub-scenes, made by a calibration observation being interposed between them, have the same observation mode, they are concatenated to make a single sub-scene. Scenes will not be divided to sub-scenes even when observation parameters of FTS such as exposure time (1, 2, or 4 seconds) and/or scan mode (1, 3, 5, 7, or 9 points observation) are changed. On the contrary, multiple times of observation of the same place may be separated into different sub-scenes when the observations were conducted using different modes such as daytime / nighttime observations.

(2) FTS scan

An interferogram obtained in a single observation is defined as an FTS scan. The FTS scan is a minimum unit of FTS observation. One scene of the FTS Level 1 product includes 22 to 23 FTS scans.

(3) CAI scene

A CAI scene is defined to have a span covered by the observation performed in one-revolution; the start of the scene corresponds to the ascending node. A scene of CAI data is the unit to archive CAI Level 1A products. TANSO-CAI usually acquires data of the daytime area on the ground; accordingly, a CAI scene has a stretch of data for the continuous daytime area (nighttime areas are not included). Fig. 6.1-2 shows schematically how the CAI scenes are defined.

(4) CAI frame

A frame of CAI is defined by dividing the whole length of GOSAT's trajectory mapped on the ground surface into 60. A frame of CAI data is the minimum unit to archive CAI Level 1B, Level 1B+, and most of Level 2 products. As shown in Fig. 6.1-2, the center of the 31st frame is so located as it corresponds at the descending node on the equator.

(5) Miscellanies

TANSO-FTS Level 2 product data are stored on-demand basis in accordance with conditions indicated by a user, with one FTS scan taken as a basic archive unit. On the other hand, Level 3 and Level 4 product data are archived for the whole globe as a unit in general. However, the Level 3 global normalized difference vegetation index data are provided for each of the rectangles (see chapter 6.6-7).

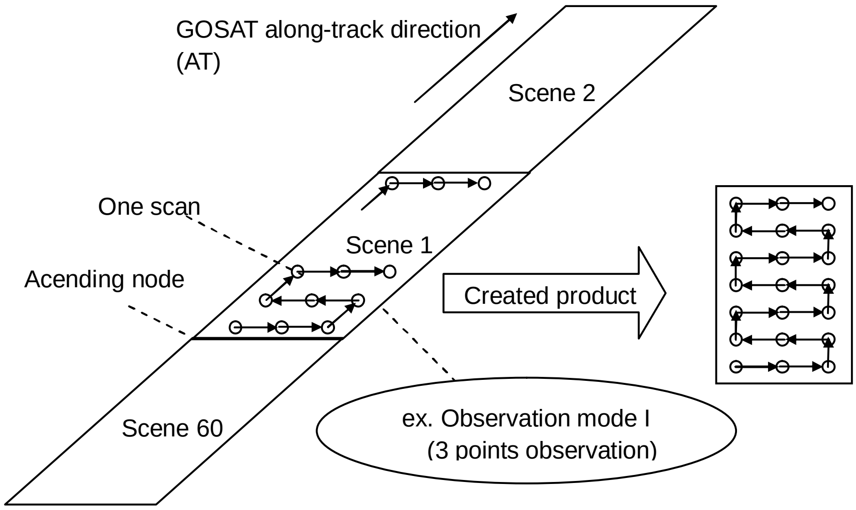


Fig. 6.1-1 Definition of FTS scene

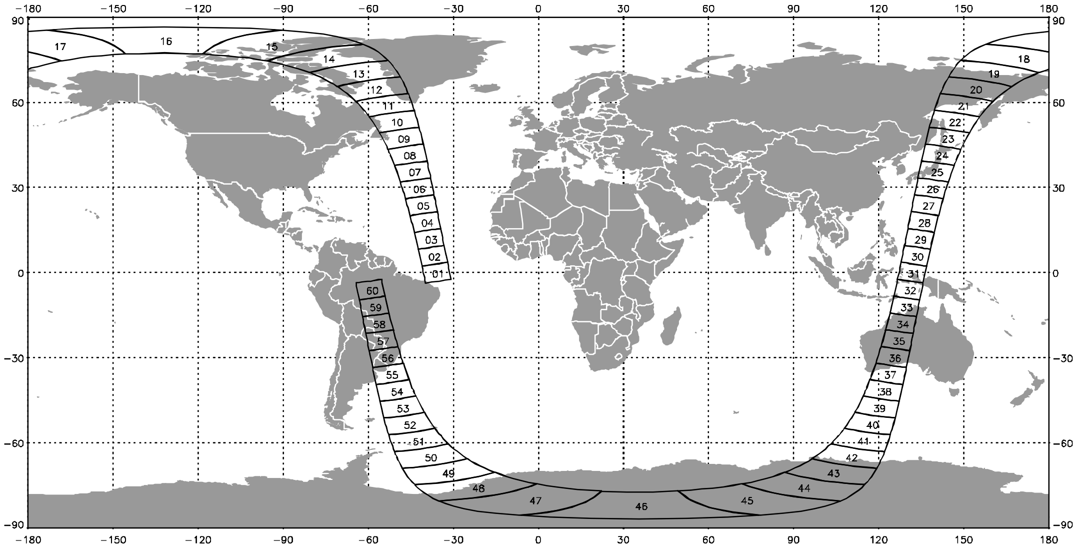


Fig. 6.1-2 CAI scene and frame definition (Path 5)

(Numerals in the figure are frame numbers.)

6.2 Products List

Each GOSAT product has its own level. The level signifies the processing stage the product has undergone. To be more specific, Level 1 products are generated by transforming voltage and current values measured by the sensors into physical quantities; Level 2 products, such as greenhouse gas column amount, are generated by processing the Level 1 product; FTS Level 3 products are obtained by applying statistical processing to the FTS Level 2 products covering a certain period of time to know the distribution over the globe; and Level 4 products (absorption and emission of the GHG and their three-dimensional concentration) are obtained through the processing of the level 2 products.

In addition, the GOSAT products are classified into three categories (standard, research, internal); any of the GOSAT products is a member of one of these categories. The definitions of product categories are described below; Table 6.2-1 is a list of the GOSAT products; and Fig. 6.2-1 shows processing flow of the products.

Since this handbook mainly focuses on the standard products, descriptions on the research and internal products are mentioned only to help understand the standard products.

- Standard products

Provided to all users upon completion of calibration, validation, or comparison[6]. JAXA, NIES, and MOE guarantee the accuracy of the products.

- Research products

Provided to limited users for their researches on calibration/validation, data processing algorithms, data application, various fields of science, etc.
The research products are not provided to general users.

- Internal products

Provided to limited number of researchers and research organizations who are engaged in collaborative research on the method for calibration or on the FTS Level 1 processing algorithm; these products are made for internal use of JAXA and/or NIES.
The internal products are not provided to general users.

[6] Details of the calibration and validation are described in section 6.7. Comparison here means a method of validating Level 3 or Level 4 products which is equivalent to the method of Level 2 validation.

Table 6.2-1 GOSAT product list

Sensor / Band		Product Level	Product name	Product category	Product unit	Data format
FTS		L1A	FTS L1A data	Internal	FTS scene	HDF5
			FTS L1A calibration data	Internal	FTS scene	
			FTS L1A lunar calibration data	Internal	FTS scene	
		L1B	FTS L1B data	Standard	FTS scene	
			FTS L1B calibration data	Internal	FTS scene	
			FTS L1B lunar calibration data	Internal	FTS scene	
	SWIR	L2	L2 CO_2 column amount (SWIR)	Standard	Option (on demand)	
			L2 CH_4 column amount (SWIR)	Standard		
			L2 H_2O column amount (SWIR)	Research		
	TIR		L2 CO_2 profile (TIR)	Standard		
			L2 CH_4 profile (TIR)	Standard		
			L2 CO_2 column amount (TIR)	Research		
			L2 CH_4 column amount (TIR)	Research		
			L2 temperature profile (TIR)	Research		
			L2 H_2O profile (TIR)	Research		
			L2 H_2O column amount (TIR)	Research		
	SWIR	L3	L3 global CO_2 distribution (SWIR)	Standard	Globe (monthly average)	
			L3 global CH_4 distribution (SWIR)	Standard		
	TIR		L3 global CO_2 distribution (TIR)	Standard		
			L3 global CH_4 distribution (TIR)	Standard		
CAI		L1A	CAI L1A data	Internal	CAI scene	
			CAI L1A calibration data	Internal	CAI scene	
			CAI L1A lunar calibration data	Internal	CAI scene	
		L1B	CAI L1B data	Standard	CAI frame	
		L1B+	CAI L1B+ data	Standard		
		L2	L2 cloud flag	Standard		
			L2 cloud property	Research		
			L2 aerosol property	Research		
		L3	L3 global radiance distribution	Standard	Globe (every 3 days)	
			L3 global reflectance distribution (clear sky)	Standard		
			L3 global cloud property	Research	Globe (monthly average)	
			L3 global aerosol property	Research		
			L3 global NDVI	Standard	Rectangle (latitude 30° × longitude 60°) (every 15 days)	
-		L4A	L4A global CO_2 flux	Standard	Global 64 regions (annually)	Text / Net CDF
			L4A global CH_4 flux	Research		
-		L4B	L4B global CO_2 distribution	Standard	Global 2.5°×2.5°mesh (monthly)	Net CDF
			L4B global CH_4 distribution	Research		

✓ Yellow-shaded products are standard ones available for general users as of December 2010.
Release schedule of the standard products, which is not open to the public, is shown in below.
FTS L2 CO_2/CH_4 profile (TIR): RA is open now. In the fall of 2011, it will be open to the public.
FTS L3 global CO_2/CH_4 distribution (TIR): In the fall of 2011, it will be open to the public.
CAI global reflectance distribution (clear sky): RA is open now. In the summer of 2011, it will be open to the public.
CAI L3 global NDVI: RA is open now. In the summer of 2011, it will be open to the public.
L4A global CO_2 flux: The public release is not determined.
L4B global distribution: The public release is not determined.

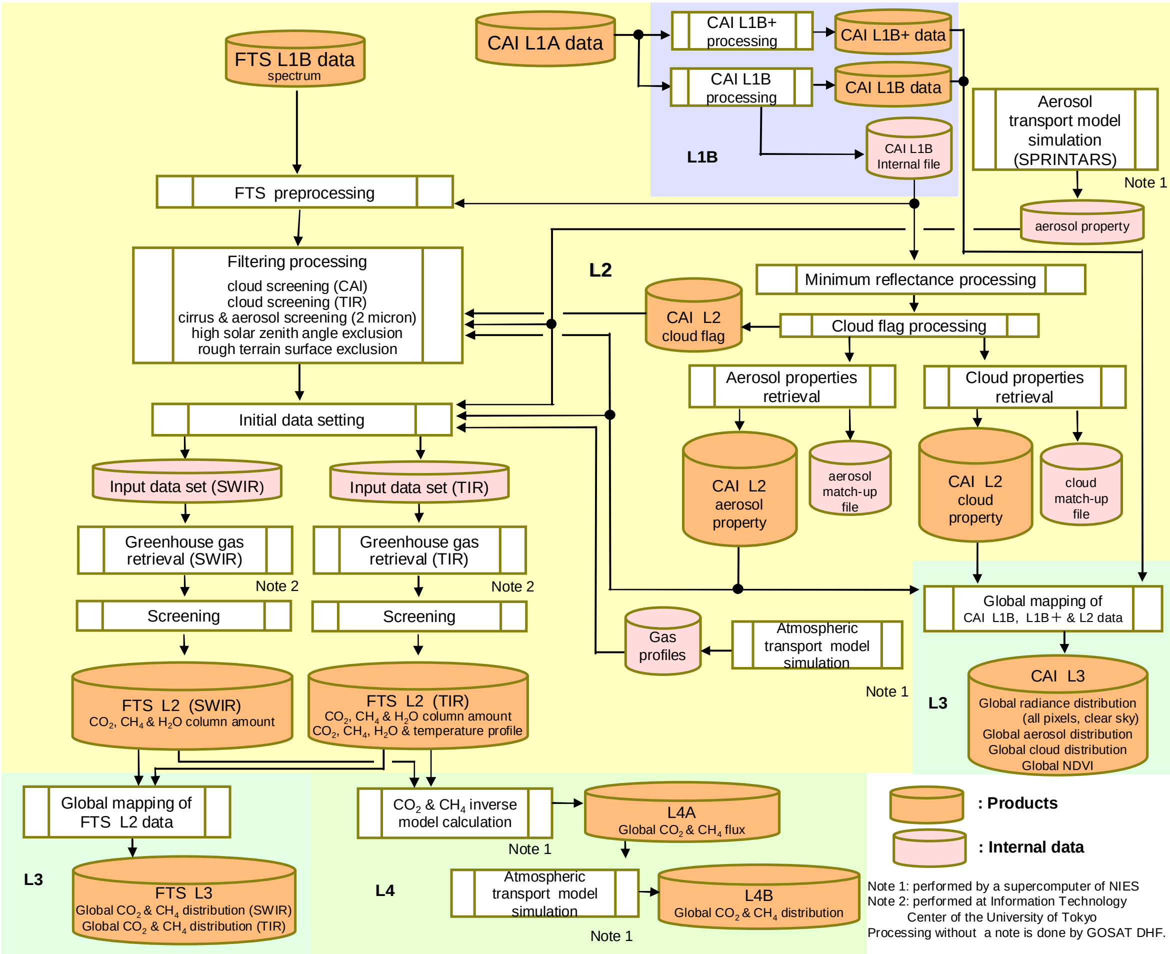


Fig. 6.2-1 Data Processing Flow of the GOSAT Products

Outlines of the standard products, which are available for general users, are described below (note that some products are not available as of December 2010). Although Level 1A products are not standard ones, descriptions for the Level 1A products are also given because they are essential to Level 1B and higher level processing as the basic input data.

6.2.1 Level 1 Products

(1) TANSO-FTS Level 1A product

TANSO-FTS Level 0 data have, in addition to the observed interferogram data (see Fig. 6.2-2), GPS data, attitude data, and so forth. Based on these data, TANSO-FTS Level 1A product is made by appending geolocational data of the observed point, radiometric correction information, etc. to the interferogram.

Daytime/nighttime observation products are created by a unit of scene as defined in Section 6.1. As for the specific observation product, a series of specific observation data are combined into one product to make a specific observation product. However, if a specific point observation is conducted crossing the boundary of sunlit/shadow areas, the product is divided into two at the boundary.

The TANSO-FTS Level 1A products are not provided for general users.

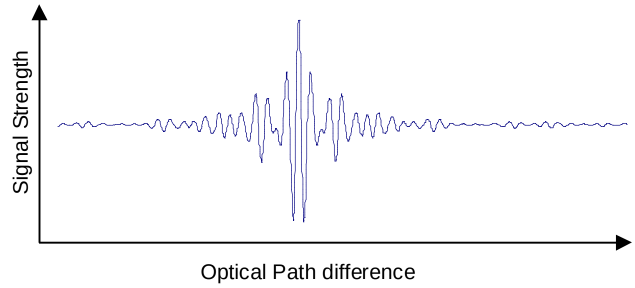


Fig. 6.2-2 Example of FTS Level 1A product (interferogram)

(2) TANSO-FTS Level 1B product

The interferogram data of TANSO-FTS Level 1A product are transformed into spectral data of each wavenumber through the Fourier transform, and thereafter undergo radiometric correction to create a TANSO-FTS Level 1B product. The Level 1B product includes spectral information of the calibration data applied to the radiometric correction. One Level 1B product is created from a Level 1A product.

Fig. 6.2-3 shows an example of FTS Level 1B product (after initial calibration) and absorption bands of greenhouse gasses. The spectrum on the top is the result of simulation integrating the spectra of Bands 1, 2, and 3.

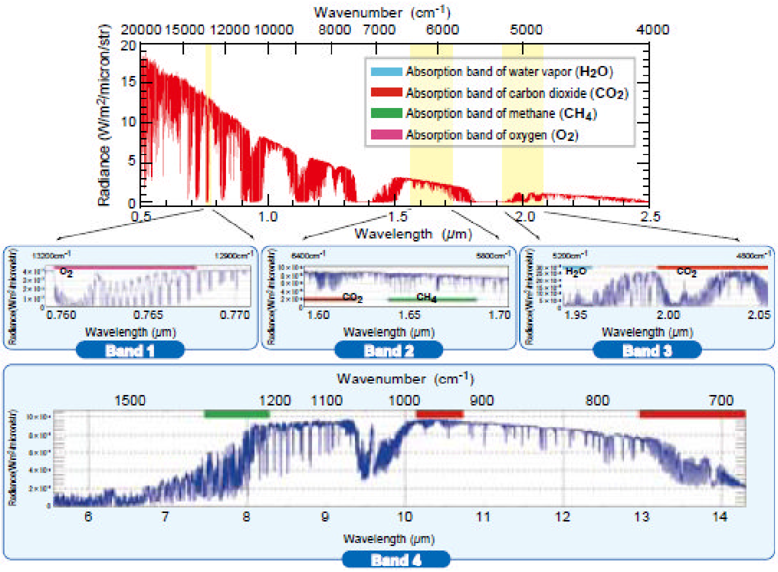


Fig. 6.2-3 Example of FTS Level 1B product (spectra) and absorption bands of greenhouse gasses

(3) TANSO-CAI Level 1A Product

TANSO-CAI Level 1A product is made by appending geolocational data of the observed point, radiometric correction information, etc. to a TANSO-CAI Level 0 data. The product is created by a unit of CAI scene as defined in Section 6.1.

The TANSO-CAI Level 1A products are not provided for general users.

(4) TANSO-CAI Level 1B Product

TANSO-CAI Level 1B product is a product having radiance information made from a Level 1A product through the conversion process using calibration coefficients. The TANSO-CAI Level 1B product includes band-to-band registration and geometric correction (map projection conversion not applied yet). The product is generated for each unit of CAI frame as defined in Section 6.1.

Fig. 6.2-4 shows an example of CAI Level 1B product. The data was observed on July 17, 2010 (after initial calibration) covering mainland Japan. This image is generated by assigning bands 1, 2, and 3 to Blue, Red, and Green respectively.

Fig. 6.2-4　Example of CAI Level 1B product

(5) TANSO-CAI Level 1B+ Product

TANSO-CAI Level 1B+ product is a product of radiance data obtained from a TANSO-CAI Level 1B product by applying band-to-band registration correction and geometric correction including map projection. The product is generated for each unit of CAI frame as defined in Section 6.1.

Fig. 6.2-5 shows an example of CAI Level 1B+ product. The data was observed on July 17, 2010 (after initial calibration) covering mainland Japan. This image is generated by assigning bands 1, 2, and 3 to Blue, Red, and Green respectively.

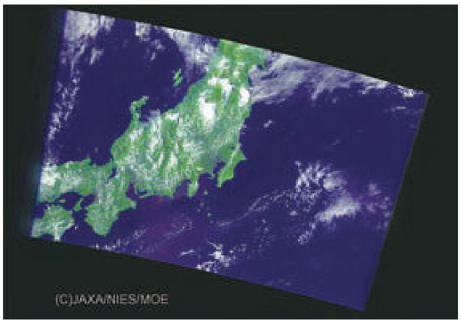


Fig. 6.2-5 Example of CAI Level 1B+ product

6.2.2 Level 2 Standard Products

(1) Level 2 CO_2 column amount (SWIR) and Level 2 CH_4 column amount (SWIR)

These two products respectively represent the column amount of carbon dioxide (CO_2) and methane (CH_4), processed from the spectra of shortwave infrared (SWIR) data (Bands 1 to 3) of TANSO-FTS, and the column-averaged dry air mole fractions of CO_2 and CH_4 (hereinafter referred to as XCO_2 and XCH_4 respectively), calculated by dividing the total column amounts of CO_2 and CH_4 by the dry air column amount. The products are generated on the demand from a user specifying the region and time of his/her interest; all the scans of interest are searched out and recorded in a file as a product.

Fig. 6.2-6 shows an example of Level 2 CO_2 column amount (SWIR) product (XCO_2), a global distribution map calculated by averaging the data of cloud-free observations for every mesh of 2.5 x 2.5 degrees. Likewise, Fig. 6.2-7 shows an example of Level 2 CH_4 column amount (SWIR) product (XCH_4). Both of them are calculated from the data observed in July, 2010; the blank portions indicate the data that were not processed due to the cloud etc.

As shown in Fig. 6.2-6 and Fig. 6.2-7, the actual column amount calculated from observation data is about 2-3% of the total observations due to the cloud etc. The XCO_2 included in these products have negative bias of 2 ~ 3 % against the validation data and standard deviation of 1 ~ 2 %. The XCH_4 also has negative bias of 1 ~ 2 % and standard deviation of 1 ~ 2 %.

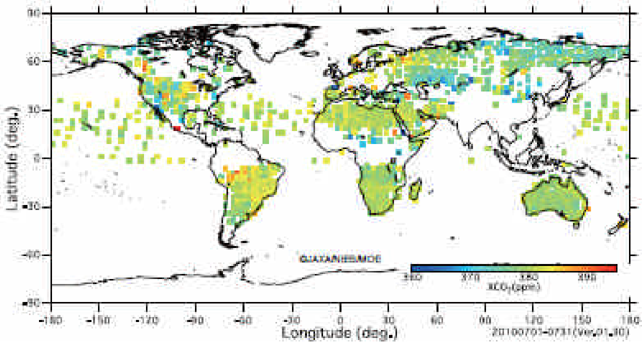


Fig. 6.2-6　Example of Level 2 CO_2 column amount (SWIR) product (XCO_2)

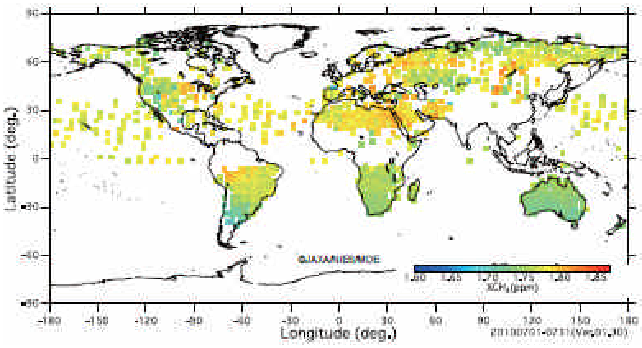


Fig. 6.2-7　Example of Level 2 CH_4 column amount (SWIR) product (XCO_4)

(2) Level 2 CO_2 profile (TIR) and Level 2 CH_4 profile (TIR)

These two profiles represent vertical distribution of the concentration of carbon dioxide (CO_2) and methane (CH_4) respectively; the profiles are obtained using a spectrum of thermal infrared (TIR/band 4) of TANSO-FTS.

(3) Level 2 cloud flag

Level 2 cloud flag product contains clear-sky confidence level which is the basic information to determine cloud flags; each of the confidence levels is stored for each of the pixels taken by CAI based on the radiance information of CAI Level 1B data.

Fig. 6.2-8 shows an example derived from CAI Level 2 cloud flag product by assuming the threshold to be 0.3. The data was observed on July 17, 2010 (after initial calibration) covering mainland Japan. The blackened parts represent clouds on the background image of CAI Level 1B introduced by Fig. 6.2-4.

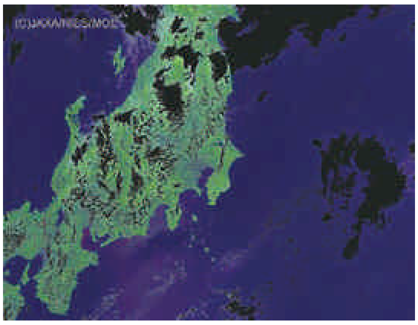


Fig. 6.2-8 Example of Level 2 cloud flag product

6.2.3 Level 3 Standard Products

(1) Level 3 global CO_2 distribution (SWIR) and Level 3 global CH_4 distribution (SWIR)

These products are generated from the level 2 column amount products (SWIR). By applying a statistical method called kriging method[7] to the Level 2 column average concentration data, a monthly average of global concentration distribution (2.5 × 2.5 degrees of grid as a unit) of greenhouse gasses can be estimated for a region near the observation point even when the region itself has no processed point.

As an example of Level 3 global XCO_2 distribution (SWIR) product, Fig. 6.2-9 shows a global distribution map in which the data of the product are visualized and mapped. Likewise, Fig. 6.2-10 shows an example of Level 3 global XCH_4 distribution (SWIR) product. Both of the observation data were acquired on July, 2010, and the whitened portions represent the places where the data do not exist within 500km measured from the processed points.

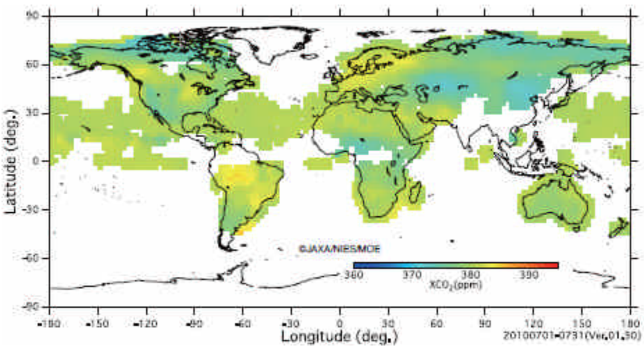


Fig. 6.2-9 Example of Level 3 global CO_2 distribution (SWIR) product (XCO_2)

[7] A method to estimate a value with the least error for a position using the known values in its neighbor.

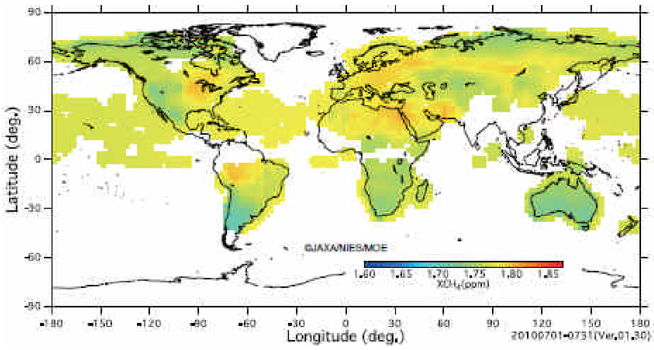


Fig. 6.2-10　Example of Level 3 global CH_4 distribution (SWIR) product (XCO_4)

(2) Level 3 global CO_2 concentration (TIR) and Level3 global CH_4 concentration (TIR)

These products are generated from the TIR Level 2 concentration profiles. Distribution of GHG concentration on multiple equi-pressure planes supposed in the atmosphere is estimated by a statistical method derived by using the kriging method.

(3) Level 3 global radiance distribution (with cloud)

Level 3 global radiance distribution product is a product generated from Level 1B+ data of three consecutive days observed by TANSO-CAI. It is a global radiance map product to demonstrate the global distribution of radiance from the earth surface and cloud.

Fig. 6.2-11 is an example of Level 3 global radiance distribution product. The image was generated from the observation data of three consecutive days, i.e. July 15 through 17, 2010; bands 1, 2, and 3 are assigned to colors Blue, Red, and Green respectively.

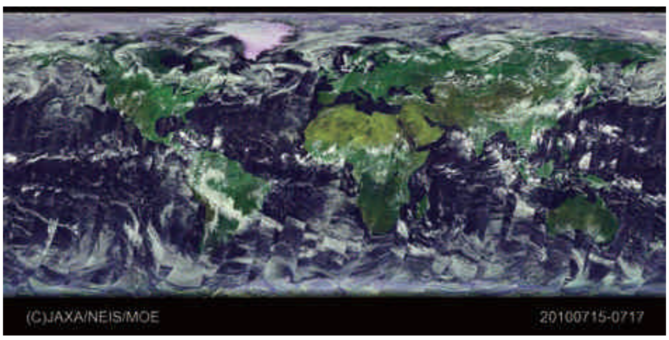


Fig. 6.2-11　Example of Level 3 global radiance distribution product

(4) Level 3 global reflectance distribution (clear sky)

Level 3 global reflectance distribution (clear sky) product is a global map product of ground surface reflectance generated from TANSO-CAI Level 1B data. This product is generated by taking a minimum reflectance derived from TANSO-CAI data for a month. As a result, the data seems to have no cloudy pixel.

Fig. 6.2-12 is an example of Level 3 global reflectance distribution (clear sky) product. The image is generated from the data acquired on July 1st through 31st, 2010; bands 1, 2, and 3 are assigned to colors Blue, Red, and Green respectively.

Fig. 6.2-12 Example of Level 3 global reflectance distribution (clear sky) product

(5) Level 3 global NDVI

This product is a global map product of Normalized Difference Vegetation Index (NDVI) that is calculated from the radiance data of TANSO-CAI bands 2 and 3 observed for five recurrent cycles (15 days). The whole globe is divided into rectangles of 60 × 30 degrees (6 divisions in the longitudinal direction, and 6 divisions in the latitudinal direction); each rectangle is composed of meshes of 0.05 × 0.05 degrees (14,400 × 7,200 meshes).

6.2.4 Level 4 Standard Products

(1) Level 4A Global CO_2 flux

The uptake and release (flux) of CO_2 in each of 64 sub-continental regions is estimated from CO_2 column-averaged mixing ratios (stored in the Level 2 FTS SWIR product) and CO_2 observational data collected in a network of ground-based monitoring stations. This product is generated by using an atmospheric tracer transport model that simulates the advection of CO_2 by wind.

(2) Level 4B global CO_2 distribution

The Level 4B product stores three-dimensional distributions of CO_2 concentration (6-hourly; 2.5×2.5 degrees horizontal resolution) that are derived from the Level 4A global CO_2 flux data. These distributions are obtained with an atmospheric tracer transport model.

6.3 Definitions of Product File Names

File name definitions of the standard products available for general users are given below.

For the product code of the products, see Table 6.3-1. For the details of the processing version, see Section 7.2.3.

(1) TANSO-FTS Level 1B product

File name of TANSO-FTS Level 1B product is defined as shown below.

1–5	G O S A T	Satellite
6–9	T F T S	Sensor
10–21	Y Y Y Y M M D D H H m m	Observation date
22–24	P P P	Pass No.
25–27	S S S	Scene No
28	X	Sub scene No.
29	_	
30–31	1 B	Processing level
32–35	a b c d	Product code
36–41	A A A P P P	Processing version
42–44	. 0 1	Extension

Scene ID: positions 1–28; Product ID: positions 30–41.

Fig. 6.3-1 File name definition of TANSO-FTS Level 1B product

(2) TANSO-CAI Level 1B product

File name of TANSO-CAI Level 1B product is defined as shown below.

1–5	G O S A T	Satellite
6–9	T C A I	Sensor
10–21	Y Y Y Y M M D D H H m m	Observation date
22–24	P P P	Pass No.
25–27	F F F	Frame No.
28	0	
29	_	
30–31	1 B	Processing level
32–35	a b c d	Product code
36–41	V M M N N 0	Processing version
42–44	. h 5	Extension

Fig. 6.3-2 File name definition of TANSO-CAI Level 1B product

(3) TANSO-CAI Level 1B+ product

File name of TANSO-CAI Level 1B+ product is defined as shown below.

1–5	G O S A T	Satellite
6–9	T C A I	Sensor
10–21	Y Y Y Y M M D D H H m m	Observation date
22–24	P P P	Pass No.
25–27	F F F	Frame No.
28	0	
29	_	
30–31	1 B	Processing level
32–35	a b c d	Product code
36–41	V M M N N 0	Processing version
42–44	. h 5	Extension

Fig. 6.3-3 File name definition of TANSO-CAI Level 1B+ product

(4) TANSO-CAI Level 2 product

File name of TANSO-CAI Level 2 product is defined as shown below.

1–5	G O S A T	Satellite
6–9	T C A I	Sensor
10–21	Y Y Y Y M M D D H H m m	Observation date
22–24	P P P	Pass No.
25–27	F F F	Frame No.
28	0	
29	_	
30–31	0 2	Processing level
32–35	a b c d	Product code
36–41	V M M N N 0	Processing version
42–44	. h 5	Extension

Fig. 6.3-4 File name definition of TANSO-CAI Level 2 product

(5) TANSO-FTS SWIR Level 2 product

File name of TANSO-FTS SWIR Level 2 product is defined as shown below.

1–5	6–9	10–17	18	19–20	21–24	25–29	30	31–40	41	42–44
G O S A T	T F T S	Y Y Y Y M M D D	_	0 2	a b c d	V M M N N	R	y y m m d d n n n n	0	. h 5
Satellite	Sensor	Start date of search		Processing level	Product code	Processing version		Product order No. (Product ordering date + serial No.)		Extension

Fig. 6.3-5 File name definition of TANSO-FTS SWIR Level 2 product

(6) TANSO-FTS TIR Level 2 product

File name of TANSO-FTS TIR Level 2 product is defined as shown below.

1–5	6–9	10–17	18	19–20	21–24	25–29	30	31–40	41	42–44
G O S A T	T F T S	Y Y Y Y M M D D	_	0 2	a b c d	V M M N N	R	y y m m d d n n n n	0	. h 5
Satellite	Sensor	Start date of search		Processing level	Product code	Processing version		Product order No. (Product ordering date + serial No.)		Extension

Fig. 6.3-6 File name definition of TANSO-FTS TIR Level 2 product

(7) TANSO-FTS SWIR Level 3 product

File name of TANSO-FTS SWIR Level 3 product is defined as shown below.

1–5	6–9	10–17	18–25	26	27–28	29–32	33–37	38–40
G O S A T	T F T S	Y Y Y Y M M D D	y y y y m m d d	_	0 3	a b c d	V M M N N	. h 5
Satellite	Sensor	Observation start date	Observation end date		Processing level	Product code	Processing version	Extension

Fig. 6.3-7 File name definition of TANSO-FTS SWIR Level 3 product

(8) TANSO-FTS TIR Level 3 product

File name of TANSO-FTS TIR Level 3 product is defined as shown below.

1–5	6–9	10–17	18–25	26	27–28	29–32	33–37	38–40
G O S A T	T F T S	Y Y Y Y M M D D	y y y y m m d d	_	0 3	a b c d	V M M N N	. h 5
Satellite	Sensor	Observation start date	Observation end date		Processing level	Product code	Processing version	Extension

Fig. 6.3-8 File name definition of TANSO-FTS TIR Level 3 product

(9) TANSO-CAI Level 3 product

File name of TANSO-CAI Level 3 product is defined as shown below.

1–5	6–9	10–17	18–25	26	27–28	29–32	33–37	38–40
G O S A T	T C A I	Y Y Y Y M M D D	y y y y m m d d	_	0 3	a b c d	V M M N N	. h 5
Satellite	Sensor	Observation start date	Observation end date		Processing level	Product code	Processing version	Extension

Fig. 6.3-9 File name definition of TANSO-CAI Level 3 product

(10) TANSO-CAI Level 3 NDVI product

File name of TANSO-CAI Level 3 NDVI product is defined as shown below.

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

G O S A T	T C A I	Y Y Y Y M M D D	y y y y m m d d	_	0 3	a b c d	V M M N N	Z Z Z	. h 5
Satellite	Sensor	Observation start date	Observation end date		Processing level	Product code	Processing version	ID (If one dataset is divided)	Extension

Fig. 6.3-10　File name definition of TANSO-CAI Level 3 NDVI product

(11) Level 4A product

File name of Level 4A product is defined as shown below. The Level 4A product will be provided in NetCDF format as well as in text files introduced here; however, file name rules for the NetCDF is not fixed yet.

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

G O S A T	T F T S	Y Y Y Y M M D D	y y y y m m d d	_	4 A	a b c d	V M M N N	. t x t
Satellite	Sensor	Start date of flux estimation	End date of flux estimation		Processing level	Product code	Processing version	Extension

Fig. 6.3-11　File name definition of Level 4A product

(12) Level 4B product

File name of Level 4B product is defined as shown below.

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

G O S A T	T F T S	Y Y Y Y M M D D	y y y y m m d d	_	4 B	a b c d	V M M N N	. n c
Satellite	Sensor	Start date of forward calculation	End date of forward calculation		Processing level	Product code	Processing version	Extension

Fig. 6.3-12　File name definition of Level 4B product

Table 6.3-1　Product code of GOSAT products

Product code	Product name
<L1>	
OB1D	FTS observation mode I, Sunlit observation data
OB1N	FTS observation mode I, Shadow observation data
OB2D	FTS observation mode II, Sunlit observation data
SPOD	FTS specific observation mode, Sunlit observation data
SPON	FTS specific observation mode, Shadow observation data
TRB0	CAI L1B data
TRBP	CAI L1B+ data
<L2>	
C01S	L2 CO_2 column amount (SWIR)
C02S	L2 CH_4 column amount (SWIR)
C03S	L2 H_2O column amount (SWIR)
C01T	L2 CO_2 column amount (TIR)
C02T	L2 CH_4 column amount (TIR)
P01T	L2 CO_2 profile (TIR)
P02T	L2 CH_4 profile (TIR)
TMPT	L2 temperature profile (TIR)
P03T	L2 H_2O profile (TIR)
C03T	L2 H_2O column amount (TIR)
CLDM	L2 cloud flag
CLDP	L2 cloud property
AERP	L2 aerosol property
<L3>	
C01S	L3 global CO_2 distribution (SWIR)
C02S	L3 global CH_4 distribution (SWIR)

Product code	Product name
P01T	L3 global CO_2 distribution (TIR)
P02T	L3 global CH_4 distribution (TIR)
TRCL	L3 global radiance distribution
TRCF	L3 global reflectance distribution (clear sky)
CLDP	L3 global cloud property
AERP	L3 global aerosol property
NDVI	CAI global NDVI
<L4>	
F01M	L4A global CO_2 flux
F02M	L4A global CH_4 flux
P01M	L4B global CO_2 distribution
P02M	L4B global CH_4 distribution

6.4 Product Format

6.4.1 Data Storage Format

GOSAT products for general users are stored in the format of HDF, text, or NetCDF, as shown in Table 6.2-1, and provided. Outlines of HDF and NetCDF are described below.

(1) HDF

HDF[8,9] (Hierarchical Data Format) is a self-descriptive generic file format designed by the National Center for Supercomputing Applications (NCSA) of U.S.A. HDF is a platform independent file format and stores multiple types of data objects necessary for data analysis and associated files into a single file, while images, charts, annotations, image palettes, etc. are included in the objects mentioned above. Meta-data, describing data types, positions of the data in the file, and so on, are also included in the file.

HDF has a hierarchical structure; the physical file format to store the data is defined as the lowest layer, while the upper layers include applications to perform operations such as HDF file management, data manipulation, validation, and analysis. HDF is not prepared for simply defining a file format but is composed of various kinds of supporting software to facilitate operations such as data storing, searching, visualizing, analyzing, and managing with the HDF file. The hierarchical structure of HDF is illustrated in Fig. 6.4-1.

HDF5, version 5 of HDF, adopted to the GOSAT products, has resolved the problems in the preceding versions; storing limit of 20,000 for the number of data sets, file size limit of 2GB for file generation, and so forth.

[8] Illustrative Remote Sensing, revised edition, p. 305, 2001
[9] The HDF Group, http://www.hdfgroup.org/

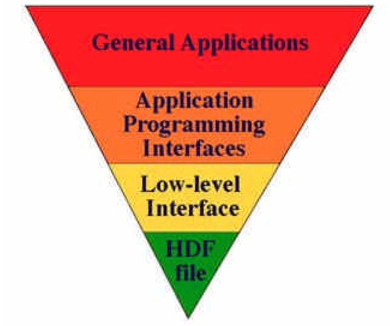


Fig. 6.4-1　Hierarchical Structure of HDF[10]

(2) NetCDF

NetCDF[11] (Network Common Data Form) is a self-descriptive, array-oriented file format, which was designed in 1989 led by Unidata of USA. NetCDF stores meta-data in addition to regular data. Like HDF5, NetCDF is not only a file format but is composed of software libraries.

Multidimensional array data can be stored in the data storage layer; the GOSAT Level 4B global CO_2 distribution product, which is three-dimensional data, is provided to users in NetCDF. There exists a close relationship between HDF5 and NetCDF. That is to say, NetCDF of version 4.1 and later adopts HDF5 format to the data storage layer, and allows read-in access to the data in HDF5.

6.4.2　Format Examples

In order to display and/or analyze a GOSAT product, it should be read in accordance with its data format. As libraries are available for HDF5 and NetCDF, the products are read-in using the libraries as a common practice.

Table 6.4-1 lists up the document names and sections explaining the format of the standard products. Further, as an example of most frequently used products, FTS Level 1B and CAI Level 1B are introduced in the paragraphs below.

[10] http://www.hdfgroup.org/products/hdf4/whatishdf.html

[11] Unidata, NetCDF-3 Users Guide for C (Japanese version) ;
http://www.unidata.ucar.edu/software/netcdf/old_docs/
Copyright © 1997 University Corporation for Atmospheric Research, Boulder,Colorado.

Table 6.4-1 Standard products and format documents

Product name	Already provided	Document name	Related section
FTS L1B product	√	TANSO Level 1 Product Description Document (technical document number: MAS-1000067)	Section 3 of TANSO-FTS Part ,
CAI L1B product	√	NIES GOSAT product format Description (document number: NIES-GOSAT-PO-006)	6.1
CAI L1B+ product	√		6.2
L2 CO_2 column amount (SWIR)	√		6.3
L2 CH_4 column amount (SWIR)	√		6.4
L2 CO_2 profile (TIR)	-		6.5
L3 global CH_4 distribution (TIR)	-		-
L2 cloud flag	√		6.6
L3 global CO_2 column average concentration (SWIR)	√		6.7
L3 global CH_4 column average concentration (SWIR)	√		6.8
L3 global CO_2 distribution (TIR)	-		6.9
L3 global CH_4 distribution (TIR)	-		-
L3 global radiance distribution	√		6.10
L3 global reflectance distribution (clear sky)	-		-
L3 global NDVI	-		-
L4A global CO_2 flux	-		-
L4B global CO_2 distribution	-		-

- ✓ Documents in the table can be obtained from the NIES GOSAT products distribution site GUIG. For further information please refer to Section 7.3.1.
- ✓ The symbol "√" for the column “Already provided” indicates that the product is available as of December 2010, whereas the symbol "-" means the product is not available yet. The symbol "-" for the column “Related section” indicates that the product format is not open to the public as of December 2010.

(1) An example of FTS Level 1B product

Among the various data sets of the FTS Level 1B products, as the ones frequently made use of, explanation follows for the geometric information and radiance information of the observed point to help understand how they are configured.

Further details are available in Section 3 of the Part TANSO-FTS in "TANSO Level 1 Product Description Document (technical document number: MAS-100067)."

a. Geometric information of the observation point

"Geometric information of the observation point" is configured as described below to indicate observation locations and conditions.

- Latitude of observation point : /exposureAttribute/pointAttribute/geometricInfo/centerLat
- Longitude of observation point :
  /exposureAttribute/pointAttribute/geometricInfo/centerLon

- Incidence angle of observation point : /exposureAttribute/pointAttribute/geometricInfo/AOI
- Azimuth of observation point : /exposureAttribute/pointAttribute/geometricInfo/AZ
- Solar azimuth of observation point : /exposureAttribute/pointAttribute/sun/AZ
- Solar elevation of observation point : /exposureAttribute/pointAttribute/sun/EL
- Land or sea flag : /exposureAttribute/pointAttribute/geometricInfo/landType

b. Radiance information of the observation point

"Radiance information of the observation point" is configured as described below to present observation data. Although a conversion table is necessary to express the data in the unit of radiance, conversion tables for Bands 1-3 are not stored in the products. Accordingly, the conversion tables are to be obtained separately from the NIES website[12].

- Band 1 spectral data (observation component) : /Spectrum/SWIR/band1/obsWavelength
- Band 2 spectral data(observation component) : /Spectrum/SWIR/band2/obsWavelength
- Band 3 spectral data (observation component) : /Spectrum/SWIR/band3/obsWavelength
- Band 4 spectral data (observation component) : /Spectrum/TIR/band4/obsWavelength

(2) An example of CAI Level 1B product

Among the various data sets of the CAI Level 1B products, as the ones frequently made use of, explanation follows for the geometric information and radiance information of the observation point to help understand how they are configured. Further details are available in Section 6.1 of " NIES GOSAT product format Description (document number: NIES-GOSAT-PO-006)."

a. Geometric Information of the observation point

"Geometric information of the observation point" to indicate observation locations and conditions is configures as described below.

- Latitude of observation point : /Data/geolocation/latitude
- Longitude of observation point : /Data/geolocation/longitude
- Height of observation point : /Data/geolocation/height
- Solar zenith angle of observation point : /Data/geolocation/solarZenth
- Solar azimuth of observation point : /Data/geolocation/solarAzimuth
- Satellite zenith angle of observation point : /Data/geolocation/satelliteZenith

[12] https://data.gosat.nies.go.jp/GosatUserInterfaceGateway/guig/techInfo/TFTSRadCnv.html

- Satellite azimuth of observation point : /Data/geolocation/satelliteAzimuth
- Land or sea flag : /Data/geolocation/landSeaMask

b. Radiance information of the observation point

"Radiance information of the observation point" is configured as described below to present observation data.

- Band 1 radiance data : /Data/radiance/band1Radiance
- Band 2 radiance data : /Data/radiance/band2Radiance
- Band 3 radiance data : /Data/radiance/band3Radiance
- Band 4 radiance data : /Data/radiance/band4Radiance

(3) An example of GOSAT HDF Viewer display

A simple GOSAT data viewer "GOSAT HDF Viewer" is provided free[13] as a display tool for the GOSAT products (HDF5 format).

The viewer reads in the data in HDF5 format and displays a group screen listing the stored data in a tree structure as shown in Fig. 6.4-2. Fig. 6.4-2 is an example reading in an FTS Level 1B product and selecting the spectrum of band 1 (a component of the observed data stored at /Spectrum/SWIR/band1/obsWavelength) as described in "6.4.2 (1) b. Radiance information of the observation point".

For the usage of GOSAT HDF Viewer, refer to the operation manual, which is open to the public together with the Viewer.

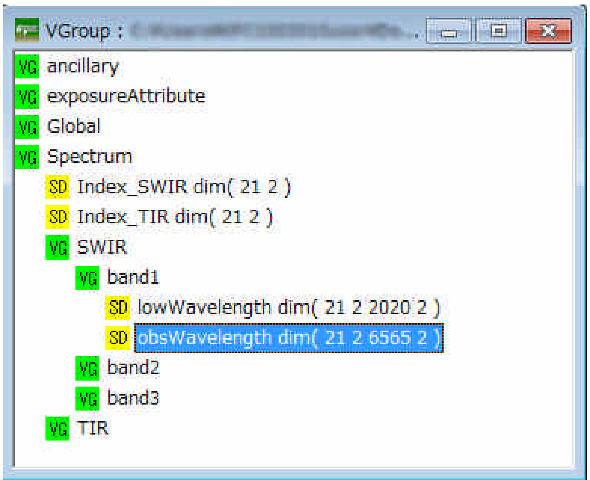


Fig. 6.4-2　Group screen of GOSAT HDF Viewer (example of an FTS Level 1B product)

[13] Research Institute of Systems Planning, Inc./ISP, http://remote-sensing.isp.jp/GOSAT-HDF/

6.5 Level 1 Processing Algorithm

Brief descriptions follow for the processing algorithm of the Level 1 product. The reference manual describing the details of the algorithm will be obtained from the NIES GOSAT products distribution website GUIG (GOSAT User Interface Gateway). The method to obtain the document is explained in Section 7.3.1.

6.5.1 TANSO-FTS Level 1A Processing Algorithm

TANSO-FTS Level 1A processing is performed on the Level 0 by adding some information to the interferogram output from the sensor. Major specifications of the appended information are listed below.

[Information appended]

- Digital count to analog value conversion factors for interferogram
- Time
- Mission telemetry data (temperature of sensor component, pointing angle of a tracking mechanism)
- Geolocation of observed points
- Position of the sun and the moon
- Land or sea flags
- Data quality information (temperature, abnormality flags concerning orbit and/or attitude data to indicate that the data are outside the threshold value, etc.)
- Ancillary data of the Level 0 data
- Information concerning orbit and attitude
- Interferogram of calibration data (of the most recent occasion for the same path; otherwise, of the next occasion to come; and still otherwise, the further next) be stored as available.
- Quality flag of interferogram
  - Saturation flag (ZPD saturation, amplitude of low-frequency components)
  - Spike noise flag (classified into 14 types, including existence / nonexistence)
  - Flag to indicate pointing mirror settlement (the angular error within 0.1 degrees, etc.), and so son
- Nonlinear correction coefficients
- Calculation method for Fourier transform[14]

A product of observation mode I holds one sixtieth of the data captured by one

[14] Processing to extract, from data signals, the information of frequency components (wavenumbers and their respective intensity).

revolution, whereas, in the case of specific observation mode, a product is made of a series of consecutive observation data. It is to be noted that Level 1A data are classified as an internal product and not open to the public.

6.5.2 TANSO-FTS Level 1B Processing Algorithm

TANSO-FTS Level 1B processing transforms the interferogram information of FTS Level 1A into spectral information through the complex Fourier transform. SWIR is transformed into spectral information in the unit of voltage per wavenumber [V/cm^{-1}], while TIR is transformed, after calibration processing, into spectrum of spectral radiance having the unit of [$W/cm^2/cm^{-1}/sr$].
With the spectral transformation, various kinds of correction (such as nonlinear correction and phase correction) are made, and additional information is appended; then, the product, thus processed per FTS scene, is stored in a file format of HDF5.
Fig. 6.5-1 is a flow of the Level 1B processing. Major specifications of the appended information and the summary of the processing shown in the processing flow are described below.

[Information appended]

- Digital count to analog value conversion factors for interferogram
- Time
- Mission telemetry data (temperature inside equipment, pointing angle of a tracking mechanism)
- Location of observed points
- Location of the sun and moon
- Land or sea flags
- Data quality information (temperature, abnormality flags concerning orbit and/or attitude data to indicate that the data are outside the threshold value, etc.)
- Ancillary information of the Level 0 data
- Information on orbit and attitude
- Phase correction information
- The range of wavenumbers or the range of differences between the light path distances which were applied to the phase correction.
- Quality flag of interferogram
  - Saturation flag (existence / nonexistence of ZPD saturation, integrated amplitude sizes of low-frequency components
  - Spike noise flag (classified into 14 types, including existence / nonexistence)
  - Flag to indicate pointing mirror settlement (the angular error within 0.1 degrees,

etc.), and so son

- Fringe count position with spike noises corrected
- Nonlinear correction coefficients
- Wavenumbers of spectrum (maximum, minimum, and number of elements)
- Calibration method for Fourier transform

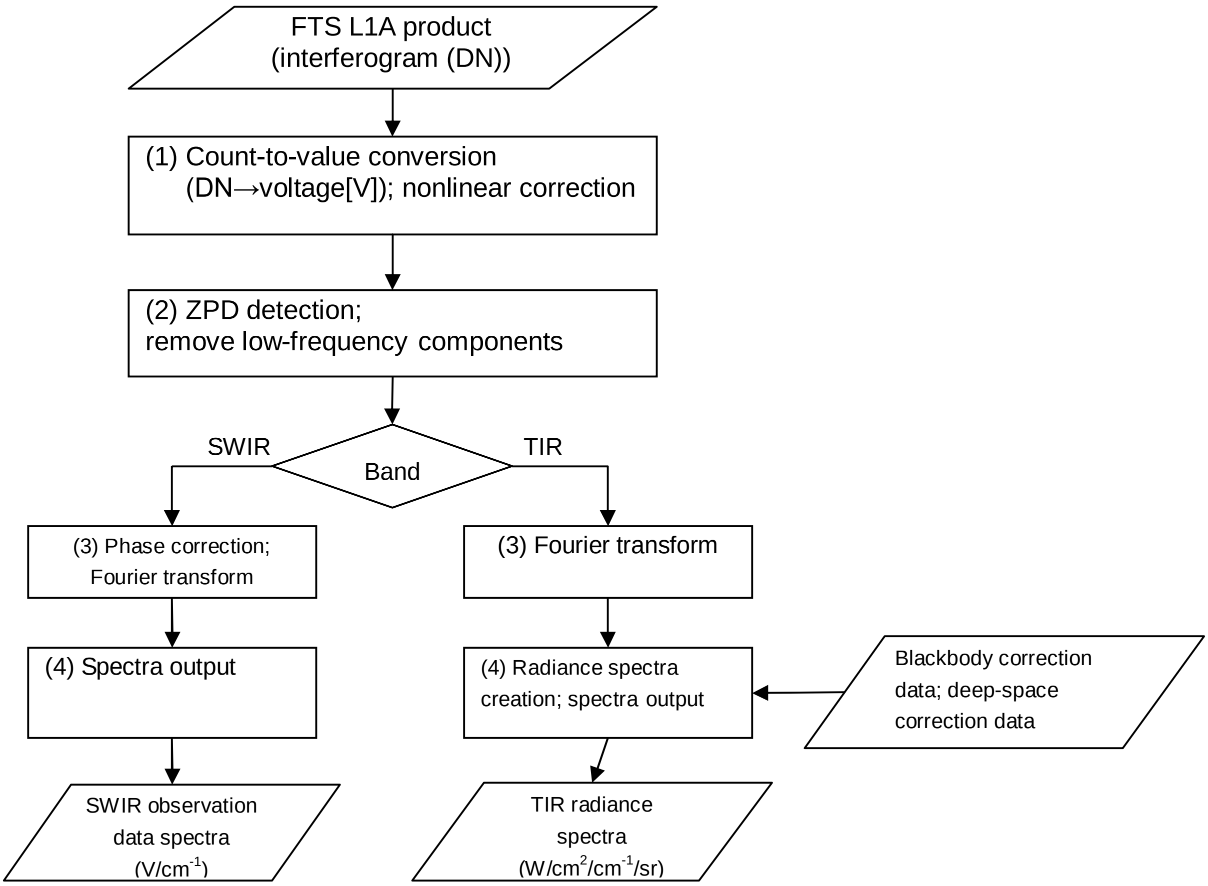


Fig. 6.5-1 TANSO-FTS Level 1B processing flow

(1) Count-to-value conversion and nonlinear correction

a. Data input

FTS Level 1A product storing the interferogram is read in.

b. Count-to-value conversion

The interferogram given as digital data is converted to analog data using a count-to-value conversion coefficient. The equation for conversion is given as a linear function.

$$I_{ANA}[m](b) = \frac{I_{DN}[m](b) - B(b,g)}{A(b,g)} \quad \text{Eq. 6.5-1}$$

$I_{ANA}[m](b)$: Interferogram of each band (analog value (voltage); output)

$I_{DN}[m](b)$: Interferogram of each band (digital value; input)

$A(b,g)$: Conversion coefficient per band, and per gain

$B(b,g)$: Offset value per band, and per offset

b : Band (b1P, b1S, b2P, b2S, b3P, b3S, b4AC, b4DC)

- P: P-polarization light, S: S-polarization light, AC: Alternating Current, DC: Direct Current

g : Gain (L, M, H)

m : Fringe count

The number of data of SWIR interferogram (Bands 1-3) is 76,336, whereas in the case of TIR (Band 4), the numbers of data of AC components and DC components are given separately, and they are 38,168 and 38, respectively.

c. Nonlinearity correction

In the case of TIR, due to the high sensitivity of PC-MCT detector, signal output of the detector tends to become nonlinear response when strong energy enter to saturate the detected signal. Accordingly, nonlinearity correction is applied to the interferogram of TIR. On the other hand, in the case of SWIR, nonlinear responses are not observed, although the nonlinear correction function itself is provided in processing.

d. Saturation check

Set the saturation flag on when a value of the interferogram, before the count-to-value conversion, exceeds the threshold value.

(2) Detection of ZPD and removal of low-frequency components

a. Removal of DC component

In general, the interferogram is composed of DC and AC components; a spectrum obtained by applying Fourier transform to the interferogram with a DC component shows a peak at the frequency of zero. In order to reduce such a peak, the DC component, being regarded as the one represented by a linear function, is removed by eliminating the linear function component, whereas the AC components, considered to be the oscillating ones, remain to undergo further processing.

b. Detection of ZPD and data extraction

After the removal of DC component, a position at which the interferogram has the maximum value is selected as the zero optical path difference point, hereafter called "ZPD". (see Fig. 6.5-2).

Next, the data shall be extracted in a way bilaterally symmetric with respect to ZPD. In order to speed up the Fourier transform that is to be executed subsequently, the number of data shall be extended to 76,545 for SWIR, and 38,400 for TIR[15]. The values for the points in the portions newly extended will be filled by 0 (zero).

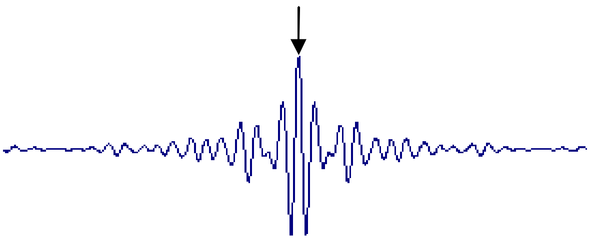


Fig. 6.5-2 Interferogram and ZPD

c. Spike noise detection and correction

Various kinds of abnormality that appear on the interferogram are processed in a lump as a spike noise. When such spike noise is detected, it is so classified as to set a noise flag on. Only in the case, however, when gain switching is detected during interferogram acquisition, correction is made using the data sampled just before the gain switching.

Since spike noises that appear on orbit are usually composed of low-frequency components, they will be removed by the low-frequency correction later discussed in the paragraph 'e' to have the defects corrected before generating the spectrum.

d. Fourier Transform

Prior to the low-frequency components elimination processing discussed in the next subsection, spectra are to be calculated from the interferogram through Fourier transform.

Since the interferogram is composed of N points of discrete signals lined up at equal intervals, the following equation of discrete complex Fourier transform is used. Each spectrum is calculated as a complex number having a real part and an

[15] Fast Fourier Transform is available by taking a larger exponent.
76,336 (=2^4×13×367) → 76,545 (= 3^7×5×7), 38,168 (=2^3×13×367) → 38,400 (=2^9×3×5^2)

imaginary part.

$$S[n] = \frac{1}{N}\sum_{m=0}^{N-1} I_{in}[m]e^{-2\pi i(mn/N)} \quad (n = 0,\ldots, N\text{-}1;\ m = 0,\ldots, N\text{-}1) \qquad \text{Eq. 6.5-2}$$

$I_{in}[m]$: Interferogram

$S[n]$: Spectrum

N : Number of data

e. Low-frequency component check and correction

Unexpected low-frequency components, which shall theoretically be zero, may appear in the spectral data when the jitter of the sensor field of view or micro-vibration of the pointing mechanism during the scanning are occurred. Accordingly, after the Fourier transform discussed in the preceding subsection, the spectral output must be checked to find if there exist any low-frequency components; and if there were some, the following correction is applied to suppress the components in the output of spectral data.

To start with, compose the spectral data that include only the low-frequency components of the spectral output; then perform inverse Fourier transform on the spectral data thus composed to generate an interferogram of the low-frequency components.

Next, subtract the generated low-frequency interferogram from the original raw interferogram.

(3) Fourier transform and phase correction (spectrum calculation)

a. Phase information extraction

With the ideal Fourier interferometer, an acquired interferogram will have its maximum alternating current component at ZPD, and its shape shall be bilaterally symmetric with respect to ZPD as seen in Fig. 6.5-2. However, in actual practice, interferograms are shaped asymmetric due to the shifts in phase caused by various factors. Therefore, phase correction is applied to the interferogram to recover its symmetry.

After the low-frequency correction being applied, some of the interferogram data near ZPD are sampled out symmetrically with respect to ZPD; then Fourier transform is performed on the sampled data with a given window function to calculate a phase angle from the values of real part and imaginary part. This is the phase information held by the spectrum after the Fourier transform and before the phase correction.

b. Fourier transform and phase correction

Perform Fourier transform on the entire interferogram, to which the low-frequency correction has already been applied, to calculate spectral data. Then rotate the calculated spectrum by the phase angle obtained through the processing defined in the preceding subsection to obtain a phase-corrected spectrum in real part.

It is to be noted that phase correction is applied only to SWIR observation data, but not to TIR observation data. Instead, the calibration processing discussed in the subsection "(4) b" is applied.

(4) Generation and output of radiance spectra

a. Output of SWIR spectral data

The SWIR spectral calculation are to be processed for SWIR observation data, deep-space calibration data, blackbody calibration data, and an instrument line function calibration data. However, to avoid the calculation failure (e.g. division by zero) met in the calculation for the region of wavenumbers outside the significant range, SWIR radiance spectra are not calculated; and the observation data spectra [V/cm^{-1}] are provided as a final output.

The Level 1B product contains the complex spectral information in real part and imaginary part. The saturation flag is set when the value of the interferogram at ZPD exceeds the threshold value.

b. Output of TIR spectral data

The TIR spectral radiance [W/cm^2/cm^{-1}/sr] are calculated through the calibration processing, which is combined with 3 spectra of TIR observation data, deep space calibration data, and blackbody calibration data.

The Level 1B product contains the complex spectral information in real part and imaginary part. The saturation flag is set when the value of the interferogram at ZPD exceeds the threshold value.

6.5.3 TANSO-CAI Level 1A Processing Algorithm

Level 1A processing is a process to generate a Level 1A product using unprocessed image data output from the sensors. In the processing, 12-bit pixel data output of a sensor is converted to 2-byte digital data and stored line by line for each band. A product holds the data corresponding to one-sixtieth-length of the ground trajectory of a revolution of the satellite. The following information is stored in the product as well as the image data.

[Information appended]

- Count-to-value conversion coefficients
- Geolocation information
- Position of the sun and the moon
- Data quality information (temperature of sensor component, abnormality flags concerning orbit and/or attitude data to indicate that the data are outside the threshold value, etc.)
- Ancillary information of TANSO-CAI Level 0 data
- Information on orbit and attitude
- Information on calibration

Note that the Level 1A products are classified as an internal product and not open to the general users.

6.5.4 TANSO-CAI Level 1B Processing Algorithm

The TANSO-CAI Level 1B processing algorithm presented here is for Ver. 00.90 of the CAI Level 1B. In this version of CAI Level 1B product, the physical quantity conversion described in 6.5.4 (2) is performed, but the zero level correction, performed for CAI Level 1B+, is not performed. Therefore, the radiometric data of CAI Level 1B have different values from the CAI Level 1B+. However, in the higher level processing using the CAI Level 1B, zero level correction is performed in an intermediate step of the higher level processing.

The CAI Level 1B processing performs frame separation and physical quantity conversion on a CAI level 1A product. Furthermore, band-to-band registration correction is carried out based on band 3 with no interpolation involved. Attention must be paid to the points listed below.

- Spatial resolution at the nadir of the satellite is 0.5 km for bands 1, 2, and 3, and 1.5 km for band 4.
- The number of pixels is 2,056 for bands 1, 2, and 3, and 512 for band 4.
- Observation swath (given as a product of the spatial resolution and the number of pixels) is approximately 1,000km for bands 1, 2, and 3; while the swath for band 4 is approximately 750km, narrower than that of bands 1, 2, and 3.

The product of CAI Level 1B is provided to users by a unit of CAI frame (see

Section 6.1 (4) for details) in a file recorded in the form of HDF5 (see Section 6.3 for details) with some number of adjacent lines of data added to the frame.

Fig. 6.5-3 is a CAI Level 1B processing flow, and the brief explanation of the processing follows.

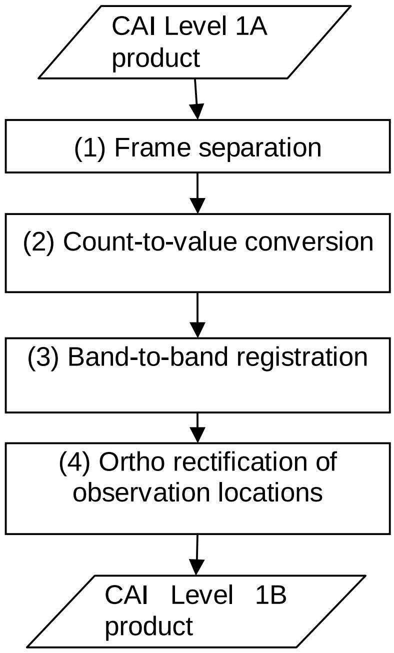


Fig. 6.5-3　CAI Level 1B processing flow

(1) Frame separation

The source data of the CAI Level 1B processing is a CAI Level 1A product file (holds a scene of observation data covered by a revolution starting from an ascending node to end at the next ascending node) and a scene of CAI Level 1A data is divided into the unit of frames commonly applied to Level 1B product; this makes it easy to keep the resolution of the source data through the processing. The central position of a frame is defined in accordance with the GOSAT nominal orbit and fixed to the ground. The average interval time between the observations of two adjacent frame centers is 98.18 seconds.

One frame usually contains TANSO-CAI observation data of 2,048 pixels × 1,355 lines (including 18 lines of an overlap with each of the adjacent frames). Fig. 6.5-4 illustrates schematically how the frame separation is made.

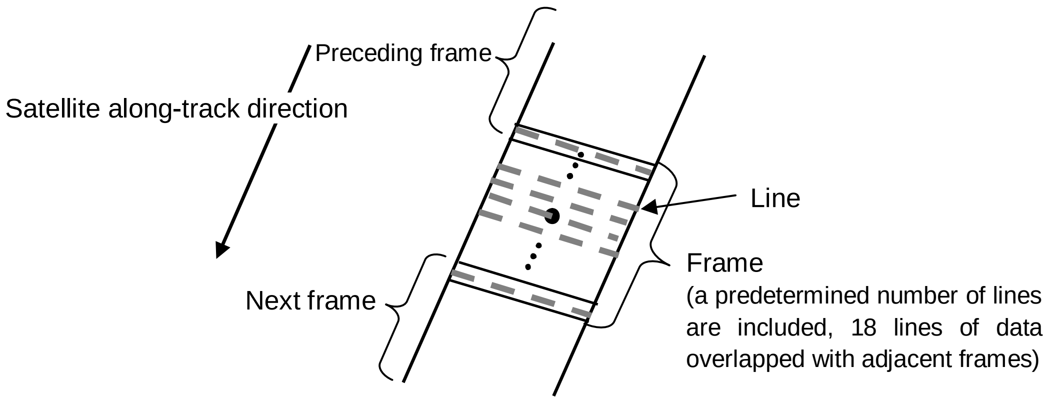


Fig. 6.5-4　Frame separation for Level 1B processing

(2) Physical quantity conversion

The physical quantity conversion processing converts CAI Level 1A product data (12-bit digital data, each ranging from 0 to 4,095) to radiance data. Further, the saturation flag is added as quality information of the CAI radiance data.

The method of converting Digital Number (DN) to radiance is described below.

$$R(i,j,k) = \frac{[DN(i,j) - Dark(i,j)]Response(i,j)}{IntegrationTime(k)} \qquad \text{Eq. 6.5-3}$$

i	: Band (1-4)
j	: Element number (1 - 2,056 for bands 1-3; 1 - 512 for Band 4)
k	: Integration time ID (0 - 31)
R(i, j, k)	: Radiance [W/m^2/sr/µm]
DN (i, j)	: CAI Level 1A product (digital value) [--]
Dark(i, j)	: Count-to-value conversion coefficient (the level in darkness) [--]
Response (i, j)	: Count-to-value conversion coefficient (responsive term) [W msec/m^2/sr/µm]
Integration Time (k)	: Integration time [msec]

Since the integration time ID in the CAI L1A is shifted in time one line backward and next line data is stored as of the corresponding digital number, this shift is corrected in the L1B data. However, for the first line of the CAI scene, since no integration time ID corresponding to its digital number exists, the integration time ID for the next line is used instead.

When an observed target is extremely bright like the clouds near the equator reflecting strong light, TANSO-CAI may become saturated. The saturation of CAI means that the digital value of the CAI Level 1A product reaches its maximum of 4,095. However, as the CAI Level 1B product is generated as a result of converting digital values to radiance, it is difficult to know whether or not saturation has occurred by only referring to the CAI Level 1B radiance data. Therefore, a saturation flag is set for each pixel of every band of L1B data and attached as information supplemental to the CAI L1B radiance data.

(For the details of the physical quantity correction, please refer to the ATBD of GOSAT-TANSO CAI Level 1B: NIES-GOSAT-PO-009)

(3) Band-to-band registration correction

In the band-to-band registration correction of CAI, the line-of-sight vector of a pixel of band 3 is taken as the reference direction; then a pixel of the band 1, whose line-of-sight vector direction is considered closest to the reference direction, is selected. Then, a pixel in band 2, and then in band 4, are selected in the same fashion.

However, band 4, having a resolution different from band 1, 2, or 3, shows a shift in the AT direction to a certain extent (several pixels' shift depending on the even/odd of a pixel). This fact was found after the launch. Accordingly, additional band-to-band registration correction processing is applied to band 4 through which pixels are shifted in the AT direction by the amount depending on the parity of pixel numbers.

(4) Ortho rectification of observed location

For a CAI Level 1B product, geometric information such as latitude and longitude is calculated taking the altitude of the location into account. This geometric correction, called ortho rectification, is carried out by calculating the position at which a line-of-sight vector intersects the surface of the Digital Elevation Model (DEM, GTOP30) and the calculated position is regarded as a point actually observed; while, in the case of CAI Level 1A, the location is calculated by calculating the intersection of the line-of-sight vector against the earth ellipsoid model. In addition, after calculating the actual location observed by each pixel, land-sea flag is given to each of the pixels to show which type of the ground, land or water (sea, lake, river), is being observed. For the data source of land-sea flags, Land-Sea Mask data is employed, which is released open to the public from the Global Land 1-KM AVHRR (Advanced Very High Resolution Radiometer) Project of the United States Geological Survey (USGS).

Since the location data in the CAI Level 1A product is given only to a pixel out of 10 x 10 pixels, the location data for each remaining pixels of CAI band 3 shall be generated by linear interpolation so that all the pixels of band 3 have observation location data (see Fig. 6.5-5).

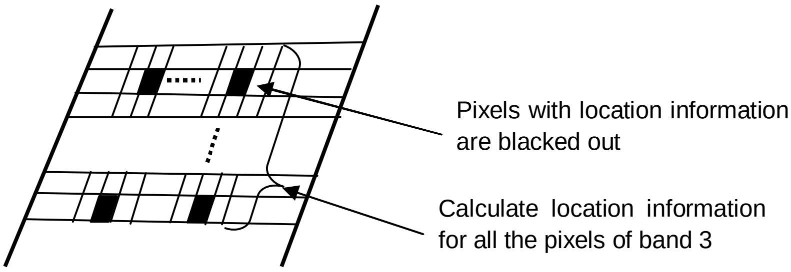


Fig. 6.5-5 Interposing observation location data

Fig. 6.5-6 illustrates schematically how the ortho rectification is conducted. The point (X' in Fig. 6.5-6) at which a line-of-sight vector intersects the ground surface defined by DEM is calculated to give the observed location corrected with the altitude taken into account. When, as in a mountainous region, the line of sight vectors intersect with several terrain surfaces, the one closest to the GOSAT satellite is selected as the observed location X'.
(As for GTOPO30, see the website of the Geographical Survey Institute.

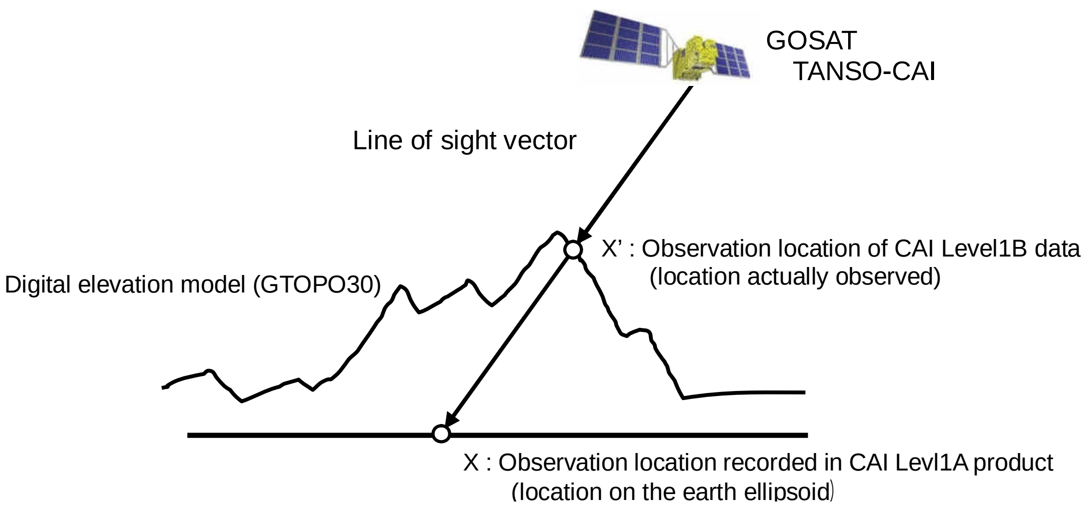


Fig. 6.5-6 Concept of ortho rectification

6.5.5 TANSO-CAI Level 1B+ Processing Algorithm

Level 1B+ processing includes frame separation, radiometric correction, and geometric correction (including ortho rectification, band-to-band registration correction, map projection) on a TANSO-CAI L1A product to generate a CAI L1B+ product by a unit of CAI frame on a file recorded in the form of HDF5. Checks on the data continuity and abnormal values are also conducted to correct the data.

Fig. 6.5-7 shows the CAI Level 1B+ processing flow, and the brief explanations of the processing will follow.

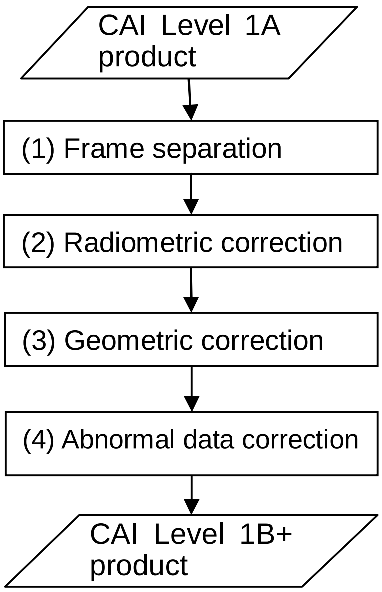


Fig. 6.5-7　CAI Level 1B+ processing flow

(1) Frame separation

The method of separation is basically the same with that of the CAI Level 1B processing. Overlapping parts between frames are 65 lines. For further information please refer to Section 6.5.4 (1).

(2) Radiometric correction

Radiance is calculated for each element of each of the bands from a digital count by using the physical quantity conversion coefficients stored in a TANSO-CAI Level 1A product.

First, physical quantity conversion, involving zero level correction and vicarious calibration correction, is performed on each element. Next, radiance is expressed in a 2-byte integer (DN value) for the places defined through the geometric correction (including band-to-band registration correction).

a. Physical quantity conversion (radiance)

Each DN value of the Level 1A product is converted to a radiance value (real number) using radiometric correction coefficients. Refer to Section 6.6.4 (2) for the outline of the processing.

b. Zero level correction

Some pixel elements placed at the edge of CAI bands 1 through 3 have no observation light coming into them because they are not in the sensor's view. The value these elements hold is taken as the level of zero and used to correct the values held by the rest of the elements receiving the light in. This processing is carried out only for Bands 1 through 3.

c. Correction by vicarious calibration coefficients

Vicarious calibration correction is a correction applied per band using the equation below. Vicarious calibration coefficients used in the equation were calculated after the launch of GOSAT, through the comparison with MODIS (MODerate resolution Imaging Spectroradiometer) sensors on board the satellite Aqua of the National Aeronautics and Space Administration (NASA).

$$R'_{ij} = R_{ij} slope + offset \qquad \text{Eq. 6.5-4}$$

i : Band number, *j* : Element number,

R : Radiance ($W/m^2/\mu m/sr$)

R ' :Radiance after vicarious calibration ($W/m^2/\mu m/sr$)

slope : Vicarious calibration coefficient (element sensitive term)

offset : Vicarious calibration coefficient (offset term)

d. Physical quantity conversion (DN value)

DN values after the correction are obtained using the equation below. This step is carried out during the re-sampling processing.

$$DN_{ij} = \mathrm{int}\left(\frac{R_{ij}}{C_{gi}} - \frac{C_{oi}}{C_{gi}}\right) \quad (DN_{ij} \geq 1) \qquad \text{Eq. 6.5-5}$$

i : Band number, *j* : Element number

DN : DN value of Level 1B+

int : Conversion to integer

C_g : Conversion factor for converting DN value of L1B+ to radiance (gain term)

C_o : Conversion factor for converting DN value of L1B+ to radiance (offset term)

Here, C_g and C_o are given as external parameters.

The value of DN is set to 1 if the calculated result of DN is less than 1, while it is set to 65,535 if the calculated result exceeds 65,535. The value 0 is used to indicate that the pixel is not valid. Fig. 6.5-8 shows an example of the case that the value 0 is utilized. If there is any blank in the image data after geometric correction, the invalid value 0 is set as DN value.

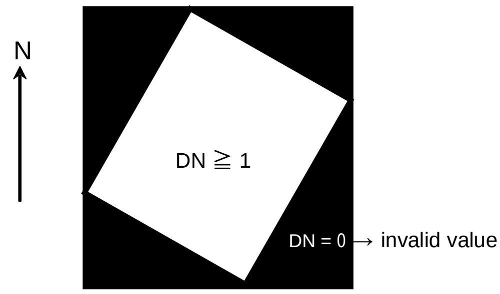


Fig. 6.5-8 Example usage of invalid value 0

(3) Geometric correction

Ortho rectification and transformation for map projection are applied to the data after the radiometric correction.

Location observed by each of the elements is calculated by determining precisely the line-of-sight vector of each pixel of each band. The pixel value, to be assigned to the positions newly defined as a result of ortho rectification and map projection, is calculated through the interpolation using the bilinear method; band-to-band registration correction is carried out as a consequence.

a. Ortho rectification

The correction method is basically the same with that of the CAI Level 1B processing. For the details of the processing, see 6.5.4 (4).

b. Transformation for map projection

Mercator projection or Polar Stereo projection is applied depending on the latitude of the frame center. In the Mercator projection, distances and areas are enlarged not proportionally when moving to higher latitude. Therefore, in the CAI L1B+ processing, the map projection is switched to the Polar Stereo projection as viewed from the North or the South Pole for the data of 60 degrees latitude or higher. For either of the map projections, the latitude on which the scale of the map is defined (called the reference latitude) and the central longitude of the map shall be specified as parameters. The parameters are set as follows.

Table 6.5-1 Map projection coverage

Map projection	Latitude ϕ range [deg]	Reference latitude	Reference longitude (orientation of map projection)
Mercator's projection	$0 \leq \| \phi \| < 60$	Equator (fixed)	Frame center (fixed)
Polar stereo projection	$60 \leq \| \phi \| \leq 90$	North latitude 90 degrees North (for frames in northern hemisphere frames) South latitude 90 degrees South (for frames in southern hemisphere frames)	Frame center (fixed)

Explanation on the procedure follows.

1) Setting of map coordinates

Following the specified projection method and parameters, geographic coordinates for the frame of each band of a Level 1A image are calculated; namely, four corner points of the frame and four middle points of the sides; a rectangular area circumscribing the four sets (each set for each band) of the eight reference points defines the area to be used for a frame. (see Fig. 6.5-9). In addition, pixel size is defined so that it has the same spatial resolution on the reference latitude.

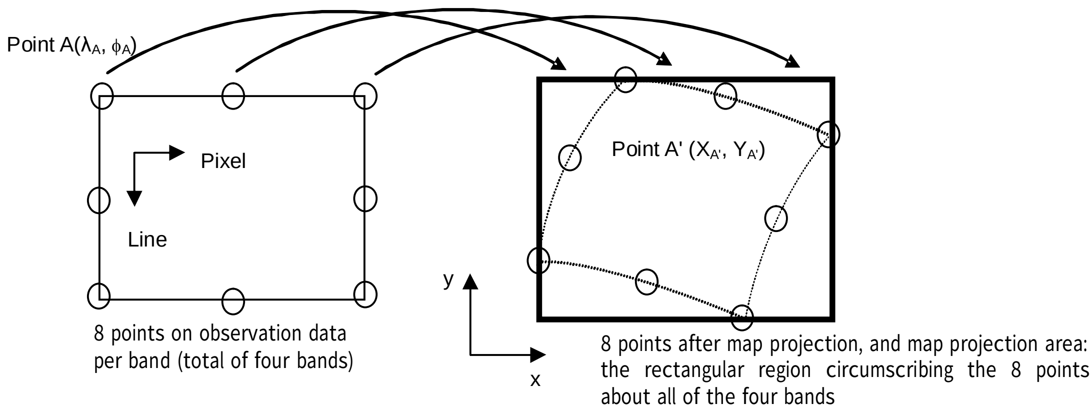


Fig. 6.5-9 Calculate map projection area

2) Calculation of Level 1B+ coordinates with regard to map coordinates

Each pixel's latitude / longitude data are calculated by the reverse map projection. In this way, line-pixel coordinates of the Level 1B+ data are associated to the latitude / longitude data. Since the reverse mapping calculation is time-consuming, the calculation is conducted for a limited number of points as called lattice points; for intermediate pixels pseudo-affine transformation is applied (see Fig. 6.5-10).

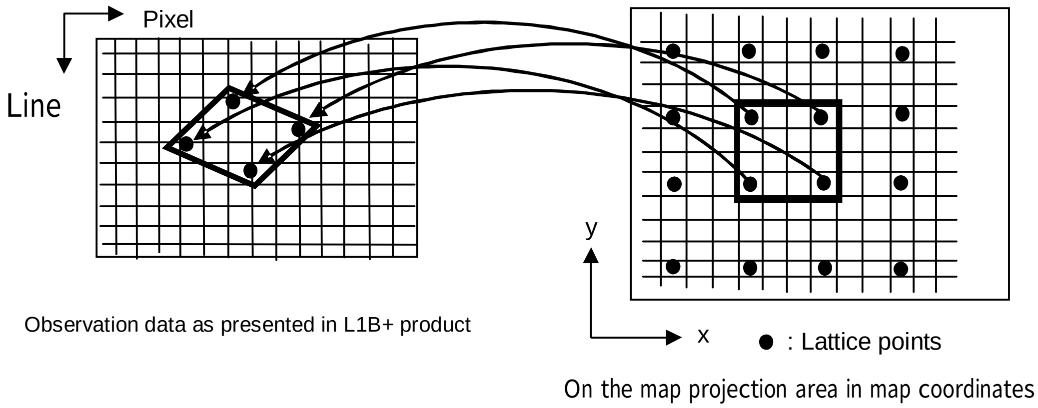


Fig. 6.5-10 Lattice points in map coordinates and their projection on Level 1B+

3) Re-sampling

In order to calculate the pixel value after the geographic mapping and to conduct band-to-band registration, bilinear re-sampling is used for interpolation.

(4) Correction for data anomaly

Abnormal data detection is conducted by the method listed below. When abnormal data are detected, they are replaced by the value calculated through the interpolation using the values on the lines before and after the scan.

(For further details, please refer to “ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) of GOSAT TANSO-CAI Level 1B+ (NIES-GOSAT-PO-011, section 5)”.

- Threshold examination: set the maximum and minimum values considered to be reasonable, and check if the data value is within the range.
- Continuity examination: check data continuity within a frame, a scan, etc; the primary purpose of this test is to detect errors caused during data transmission.
- Variability examination: when a plurality of data are included for the same item in a scan, data variability is examined; the primary purpose of the variability examination is to detect errors caused during data transmission.

(5) Miscellanies

Calculate a solar zenith and azimuth angles, and a satellite zenith and azimuth angles.

6.6　Higher level Processing Algorithm

Processing algorithm for the standard products of Level 2 or higher is outlined hereafter. For the details of algorithm, please refer to the ATBDs prepared for each algorithm.
The ATBDs are obtained from the NIES GOSAT products distribution website GUIG. How to obtain the ATBDs is explained in section 7.3.1.

6.6.1　TANSO-FTS SWIR Level 2 Processing Algorithm for CO_2 and CH_4 Column Amount

The Level 2 processing has FTS SWIR Level 1B data as input, then performs pre-processing, filtering, retrieval processing[16], and screening to calculate column amounts of carbon dioxide (CO_2) and methane (CH_4). A column amount is the number of molecules contained in a column from the earth surface up to the top of atmosphere per unit area.
Level 2 products that meet the user’s demands (observation period, observation range, etc.) are stored in a file in the form of HDF5 and provided to users. Average column concentrations are included in the products in addition to the column amounts. The column-averaged dry air mixing ratio of carbon dioxide (XCO_2) and methane (XCO_4) are calculated from the respective column amounts of carbon dioxide (CO_2) and methane (CH_4) by dividing them by the column amount of dry air. Fig. 6.6-1 shows a flow of the processing. And the outline of the processing follows. For the details of the algorithm, refer to ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR (NIES-GOSAT-PO-014). As for the details of the processing flow, refer to "Data Processing Flow for the FTS SWIR Level 2 CO_2 and CH_4 Data Products (Ver.01.xx)." Both documents are open to the public and available from GUIG.

[16] An analytical method to calculate various kinds of physical quantities from spectrum (such as height distribution of temperature and of gas molecules).

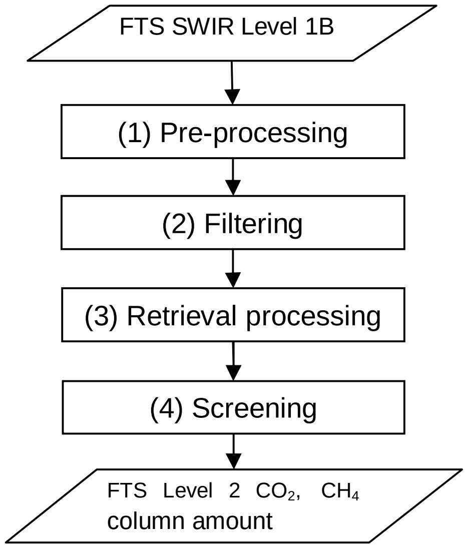


Fig. 6.6-1 Processing flow for TANSO-FTS SWIR Level 2 CO_2, CH_4 column amount

(1) Pre-processing

Before performing the retrieval processing to calculate the column amounts of carbon dioxide and methane using an FTS Level 1B product (radiance spectra), some preliminary processing is required.

As the FTS Level 1B product is made by the unit of a scene (see section 6.1 (1)), the product must be divided into units of a scan (see section 6.1 (2)) before being used as input data to Level 2 processing, while abnormal data are removed in this process.

And the time and location to the observation are calculated, then reference data such as weather information are interpolated to get the match-up data for the time and location thus identified.

(For the details of the pre-processing, see section 2 of "ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR (NIES-GOSAT-PO-014)".)

(2) Filtering (Pre-data selection)

First, some particular scans of data suitable for retrieval processing must be selected.

FTS SWIR daytime observations are conducted for about 9,000 scans per day. But not all of the data are suitable for retrieval processing. In order to get a result of high quality, the data for the processing must be confined to such data that are qualified by passing through the filtering conditions listed below.

(For the details of the filtering, see section 3 of "ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR (NIES-GOSAT-PO-014)”).

- L1 quality check (check the quality flags such as saturation flag and spike noise flag)
- Solar zenith angle check
- Ground surface undulation check
- CAI cloud coverage check
- TIR cloud coverage check

(3) Retrieval processing

The column amounts of carbon dioxide and methane are obtained by the retrieval processing.

The total column amounts of carbon dioxide and methane are estimated from the radiance spectra in a wavenumber range of 12,950 to 13,200 cm^{-1} of FTS Band 1 (oxygen sub-band), a wavenumber range of 5,900 to 6,150 cm^{-1} of FTS Band 2 (methane sub-band), and a wavenumber range of 6,180 to 6,380 cm^{-1} of FTS Band 2 (carbon dioxide sub-band). The total column amount is calculated by summing up, for all the layers, the value obtained by multiplying the average mixing ratio estimated for each layer and the corresponding dry air column amount. In addition, the column averaged volume mixing ratio (XCO_2, XCH_4) are obtained by dividing the total column amount of carbon dioxide or methane by the total column amount of dry air.

Along with the mixing ratios of carbon dioxide and methane for every layer, such physical quantities are simultaneously estimated as the average mixing ratio of water vapor for each layer, optical thickness of aerosol, atmospheric pressure on the ground, and the temperature shift.

In the calculation for the estimation mentioned above, initial values of concentration profile at the points of observation are set as the a priori data given by a simulation using the atmosphere transport model, while initial values of the aerosol are given by a simulation using the aerosol transport model SPRINTARS. Calculations are carried out repeatedly until the spectral values at the points of observation, estimated from the initial values and reference data using the analytical method, become close enough to the observed data.

(For the details of retrieval processing, see sections 4 through 8 of "ALGORITHM

THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR (NIES-GOSAT-PO-014)".)

(4) Screening (Post-screening)

Screening selection process is conducted for the data resultant from the retrieval processing described above. Only the data of good quality are selected through the screening based on the results of error evaluation, and are provided for external users as a TANSO-FTS SWIR Level 2 product. The screening conditions are cited below. Further, a processing flow including the screening is illustrated in Fig. 6.6-2. (For the details of screening, see section 9.2 of "ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR (NIES-GOSAT-PO-014)".)

- Select the data whose SNR of the synthesized polarized light is larger than 100. The SNR is defined here as a ratio of the maximum radiance of the polarization bands used in the retrieval processing to the average noise level.
- Select the data whose DFS (Degree of Freedom for Signal) is larger than 1.
- Select the data whose root mean square error of the residual spectrum is less than 3.
- Select the case where either a land area or water area is present in the sight view of TANSO-FTS (exclude the case where both a land area and water area are present in the sight view of TANSO-FTS).
- Check the presence of scattering materials of the 2-μm band.
- Select the case where the retrieval processing has converged in less than 20 times of iteration.
- Select the case where the optical thickness of aerosol, estimated with the gaseous concentration, is less than 0.5.
- With the data over the sea, select the case where the calibration coefficient adjustment value, estimated with the gaseous concentration, does not reach its upper limit 1.15 (exclude the case where the value reaches the upper limit).
- Exclude the data of Greenland and the Antarctic.
- Select the case where the index value that normalizes the evaluation function is less than 5, while the estimation of physical quantities is done through the optimization of the evaluation function.

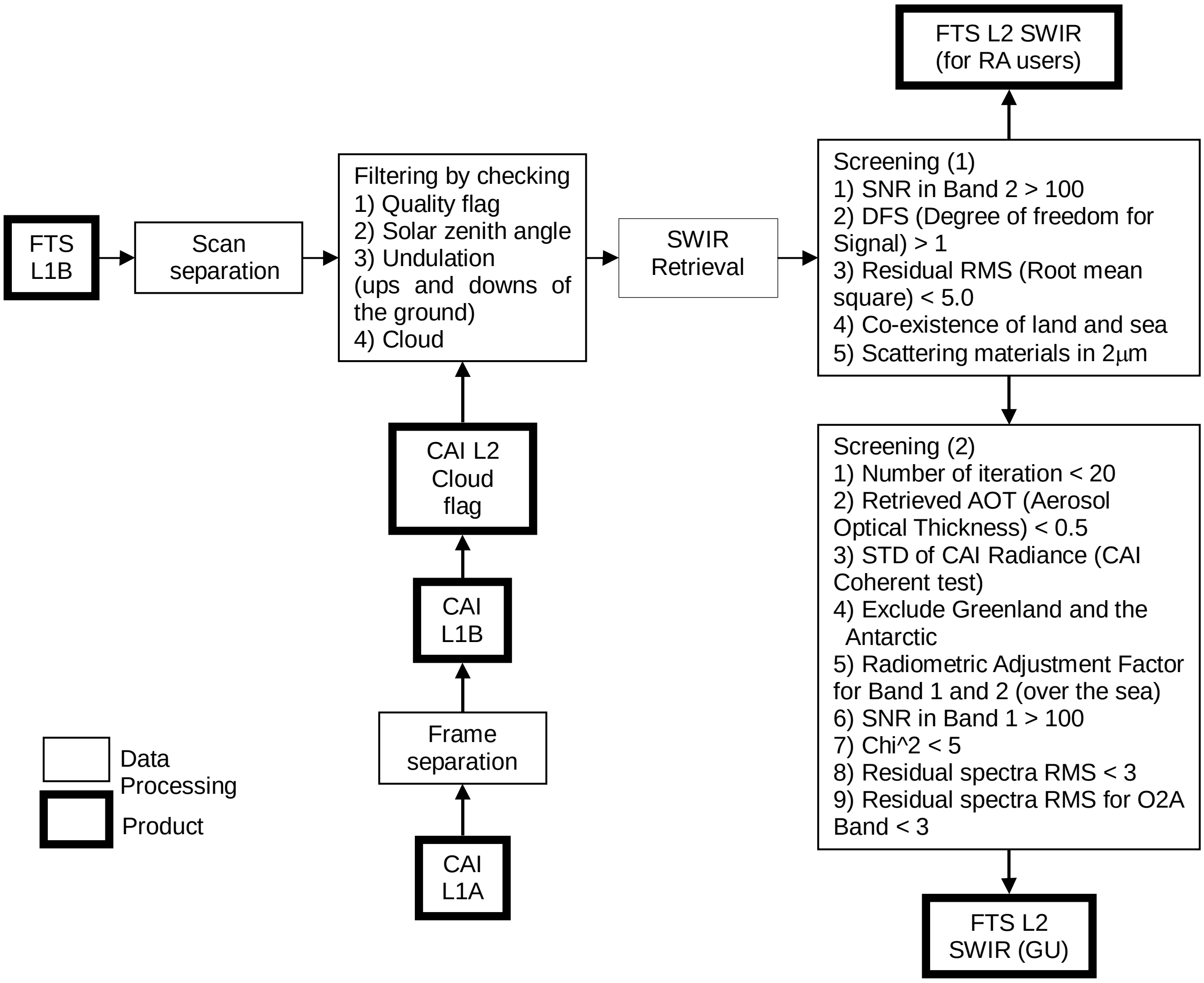


Fig. 6.6-2 Processing flow including the screening

6.6.2 TANSO-FTS TIR Level 2 Processing Algorithm for CO_2 and CH_4 Profiles

The Level 2 processing inputs FTS TIR Level 1B spectra (band 4), then performs pre-processing for retrieval, filtering by cloud screening, estimation of surface temperature and emissivity, retrieval processing, and screening by error evaluation to calculate vertical profiles and distributions of carbon dioxide and methane concentrations. A broad-band spectrum, ranging from 5.5 to 14.3μm wavelength, is acquired for the thermal infrared region; the CO_2 retrieval processing uses the absorption spectrum in 14μm band, while the CH_4 retrieval processing uses in 7μm band.

Level 2 products that meet the user's demands (observation period, observed area, etc.) are recorded in a HDf5 file and provided. Here, the profile data are calculated in seven pressure levels, which vertically change in 1,000, 700, 500, 300, 100, 50, and 30hPa of pressure height and thereabouts. However, the number of layers and the fixed layer values of pressure height recorded in Level 2 products are yet to be determined.

The processing flow is shown in Fig. 6.6-3; and the outline of the processing follows. Note that part of the pre-processing and part of the filtering are the same as those of the SWIR Level 2 processing.

For the details, see the algorithm theoretical basis documents for the TIR Level 2 processing (not available as of December 2010).

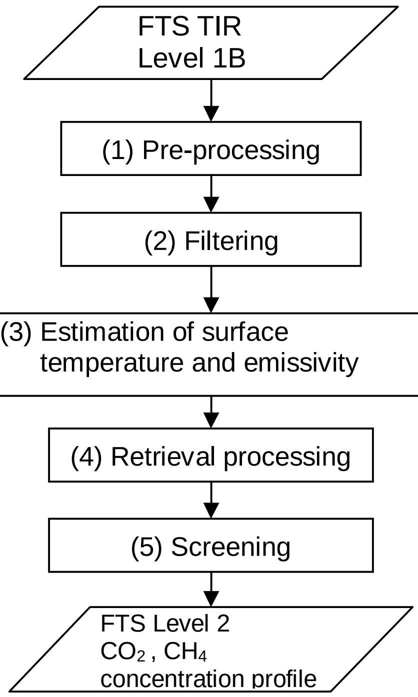


Fig. 6.6-3 Processing flow for TANSO-FTS TIR Level 2 CO_2 and CH_4 profiles

(1) Pre-processing

Preparation shall be made before performing the retrieval processing to obtain CO_2 and CH_4 concentration profiles using spectral radiance of an FTS Level 1B product. Most of the TIR pre-processing is commonly used with that of SWIR Level 2; meteorological data are of GVP, while the data initially given to the retrieval as a concentration of CO_2 and CH_4 are the predictive estimation using the NIES atmospheric transport model. For the TIR processing, climatological data are additionally required; the data listed below are prepared in the pre-processing.

- Sea surface temperature data (MODIS sea surface temperature)
- Ozone data (OMI (Ozone Monitoring Instrument) total ozone)
- Land-cover data (MODIS land-cover classification)
- Vegetation index data (CAI NDVI)

- Snow ice data (Advanced Microwave Scanning Radiometer-EOS (AMSR-E) sea ice concentration)

(2) Filtering (Pre-data selection)

The data selection for TIR retrieval processing follows suit of the SWIR filtering; namely, the data of dayside observation are adopted in the clear-sky condition based on the CAI cloud screening (CAI Level 2 cloud flag product). On the other hand, in nightside, where no CAI cloud flag is available, the TIR data for the retrieval processing are selected based on the TIR cloud screening result obtained from the TIR spectrum analysis. The slicing method and the split-window method are known for the cloud screening using TIR spectra.

(3) Estimation of surface temperature and emissivity,

Radiation from the land area changes depending on the soil type, snow and ice coverage, NDVI, etc., while on the sea area it changes depending on the sea-ice concentration, the influence of whitecaps under the sea surface wind, and so on. Therefore, the surface temperature must be estimated by supposing the initial values of the land surface emissivity based on the radiation databases (MODIS and ASTER database) with land-cover classification incorporated. The land surface temperature and emissivity thus estimated are used as an initial surface condition for the CO_2 and CH_4 retrieval processing.

(4) CO_2 and CH_4 retrieval processing

The average mixing ratios of CO_2 and CH_4 in the dry air are calculated for each layer of altitude.

In order to estimate the CO_2 and CH_4 concentration profiles from TIR data, the Maximum A Posteriori estimation (MAP estimation) based on Bayes' theorem is employed. The MAP estimation is a method to obtain a solution from the observed spectra with errors showing normal distribution by maximizing a posteriori probability while a priori probability is given as expressed by the error variance and covariance matrix. An optimum state of the atmosphere is obtained by minimizing the cost function. A nonlinear MAP estimation using Gauss-Newton algorithm is applied repetitively till the solution converges.

For the calculation of the forward spectrum used in the estimation, Line-By-Line Radiative Transfer Model (LBLRTM) and HITRAN database (HIgh resolution TRANsmission molecular absorption database) are applied so as to simulate the absorption lines of gasses in high accuracy. As a means to improve the processing speed, retrieval channels are selected in order on the basis of information contents of the target gas and layer profile.

(5) Screening (Post-screening)

Only the data of good quality are selected through the means called screening based on the results of error evaluation, and are provided for users as a TANSO-FTS TIR Level 2 product.

6.6.3 TANSO-CAI Level 2 Cloud Flag Processing Algorithm

Clear-sky confidence level, which comprises a cloud flag, is calculated from CAI Level 1B data as an input. The results are stored in a file by a unit of CAI frame in the form of HDF5.

To decrease the error in the FTS Level 2 processing, accurate cloud estimation is necessary, and the clear-sky confidence level calculated above is referred to by the FTS Level 2 processing in its filtering process with predetermined values used as a threshold to discriminate clear / cloudy conditions.

Fig. 6.6-4 is a processing flow and outline of the processing follows.

For the details of algorithm, refer to "Algorithm Theoretical Basis Document for GOSAT TANSO-CAI L2 cloud flag (NIES-GOSAT-PO-016)."

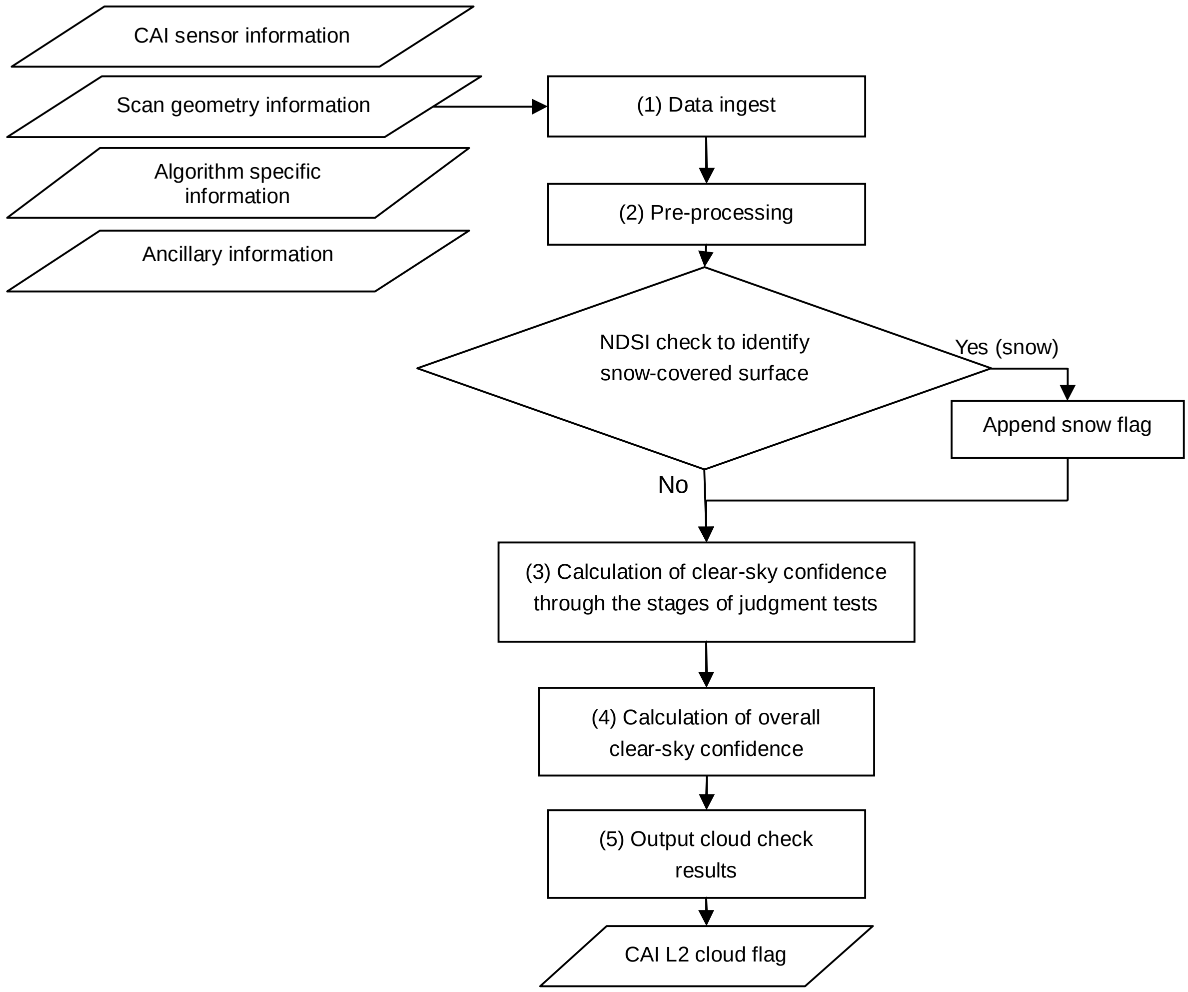


Fig. 6.6-4　Processing flow for TANSO-CAI Level 2 cloud flag

(1) Data ingest

The following data are ingested.

- CAI instrument information: CAI Level 1B data (radiance), saturation flag
- Scan's geometry information: solar zenith angle, satellite zenith angle, relative azimuth angle; latitude and longitude on the World Geodetic System (WGS84); observation time date.
- Algorithm specific information: threshold values for various judgment tests (see (3))
- Ancillary information: ground surface reflectance database for Band 2 or 3, and global land-sea flag (the 1km Land-Sea Mask supplied by United States Geological Survey). As an alternative to the former data, climatological data generated from GLI data of MODIS, ADEOS-II, etc. are used in some cases.

(2) Pre-processing

Identify day or night, land or water, and sunglint region from the input data.

In addition, calculate the reflectance from the radiance observed by CAI and solar irradiance, and the reflectance shall be used in the judgment tests explained in the paragraph (3). In the tests of (3), if any one of the saturation flags of all the bands is on, the synthetic clear-sky confidence is set to 0 (zero) because the radiance value must be saturated by cloud.

Further, check if the surface may be covered by snow using NDSI (Normalized Difference Soil Index).

(For the details of pre-processing, see section 6 (b) of "Algorithm Theoretical Basis Document for GOSAT TANSO-CAI L2 cloud flag (NIES-GOSAT-PO-016)".)

(3) Calculation of clear-sky confidence levels for each component

For the following components, clear-sky confidence level F1 is calculated.

(For the details of clear-sky confidence level calculation in each discrimination test, refer to section 6(c) of "Algorithm Theoretical Basis Document for GOSAT TANSO-CAI L2 cloud flag (NIES-GOSAT-PO-016)".)

- Test 1 : $R(B1)$ (the land area) or $R(B3)$ (the water area) → confidence level F_1
- Test 2 : $R(B3)$ / $R(B2)$ → confidence level F_2
- Test 3 : $NDVI = (R(B3) - R(B2)) / (R(B3) + R(B2))$ → confidence level F_3
- Test 4 : $R(B3)$ / $R(B4)$ (only on the land area) → confidence level F_4

R : Reflectance
B : Band
F_n : Confidence level

(4) Calculation of synthetic clear-sky confidence

The synthetic clear-sky confidence level Q is calculated from the results of respective clear-sky confidence levels F_n mentioned above in the following way:

$$Q = 1 - \sqrt{(1-F_1)(1-F_2)(1-F_3)(1-F_4)} \qquad \text{Eq. 6.6-1}$$

If confidence level Q is equal to 1, the data is considered clear. If 0, the data is considered cloudy. If one of F_n is 1, Q becomes 1, regardless of other components. The determined clear-sky confidence level is stored in the product as a 4-byte real number.

(5) Output of the cloud flag product

Cloud flags are created including the integrated clear-sky confidence level and other outputs expressed by bits. Thirty-two bits are assigned to a pixel.

(For the details of cloud flag output, see section 6 (e) of "Algorithm Theoretical Basis Document for GOSAT TANSO-CAI L2 cloud flag (NIES-GOSAT-PO-016)".)

6.6.4 Processing Algorithm of TANSO-FTS SWIR Level 3 Global CO_2 and CH_4 Distribution, and TIR Level 3 Global CO_2 and CH_4 Distribution

For the FTS Level 3 products, the whole surface of the earth is supposed to be divided into meshes of 2.5 × 2.5 degrees in the FTS Level 3 product XCO_2 or XCH_4 data estimated for each of the meshes.

These values for meshes are calculated by the kriging method using the FTS Level 2 data for a month (SWIR CO_2, CH_4 column amount, and TIR CO_2, CH_4 profile) as input.

The product is stored in a file by a unit of month in HDF5 format. As for the TIR Level 3 global CO_2 and CH_4 concentration product, the whole data are divided into seven levels based on the atmospheric pressure in vertical direction (for 1,000, 700, 500, 300, 100, 50, and 30hPa) and the data for each of the levels are separately stored; the number of layers and the pressure values to separate the layers are yet to be determined.

Fig. 6.6-5 shows the processing flow, and the outline of data processing follows.

For the details of algorithm, refer to "Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)."

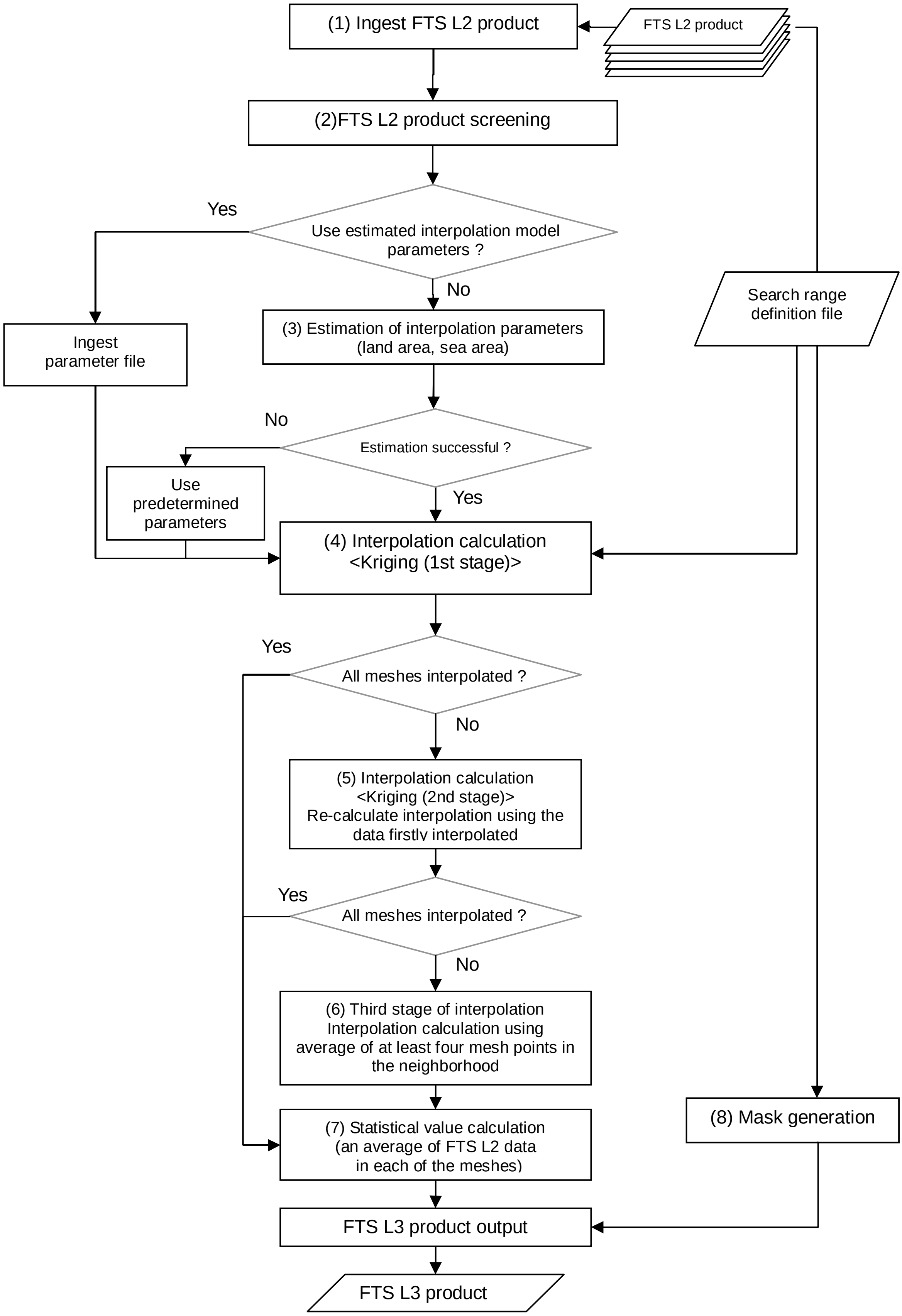


Fig. 6.6-5 Level 3 processing flow for TANSO-FTS SWIR and TIR

(1) Ingesting FTS Level 2 product

FTS Level 2 product data for a month are ingested.

(2) Screening of FTS Level 2 product

When some of the observed points in the FTS Level 2 product have a value extremely apart from the ones in their vicinity, it will have the worst effect on the accuracy of interpolation presented by the kriging method; therefore, such observation points are eliminated. This eliminating process is called screening. The screening shall be repeated till the FTS Level 2 data, thus processed, become close to normal distribution (Gaussian distribution).

(For the details of screening, see section 2.2.5 (2) of " Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)".)

(3) Estimation of interpolation model parameters

As there exists a big difference between the distribution patterns of the greenhouse gasses in "land area" and in "water area," interpolation model parameters shall be respectively estimated for the land area and water area to effectively conduct the FTS Level 3 processing.

(For the details of the estimation of interpolation model parameters, see section 2.2.5 (3) of " Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)".)

(4) Interpolation calculation < Kriging (1st stage) >

For all of the meshes, values are calculated by applying the interpolation model parameters.

Theoretically, kriging interpolation calculates values using all of the observed points (all the points in a known stochastic field). However, in the FTS Level 3 processing, kriging interpolation of the first stage is conducted on a restricted number of observation points that exist within a predetermined distance from a target mesh; the observed points, used for the interpolation, are selected by searching such points starting from the ones closest to the mesh.

However, this way of limiting the number of observation points may leave some of the mesh points with no values assigned; interpolation calculation repeated in the processing described in the paragraphs (5) and (6) are done to remove such defects by giving them values newly interpolated.

(For the details of the interpolation calculation < Kriging (1st) >, see section 2.2.5 (4) of "Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3

(NIES-GOSAT-PO-017)".)

(5) Interpolation calculation < Kriging (2nd stage) >

The second stage of kriging interpolation is applied only to the meshes where no values are given by the first stage of interpolation. On the contrary to the first stage of interpolation, there is no limit of the number of points to be used in the Kringing interpolation.

(For the details of the interpolation calculation < Kriging (2nd) >, see section 2.2.5 (5) of "Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)".)

(6) Interpolation Calculation < Kriging (3rd stage) >

The third stage of interpolation is made for the meshes left with no values even after the second stage of kriging interpolation. For this occasion, linear interpolation is applied using values of at least four meshes (already filled by values) near the mesh of the concern to give it the values.

(For the details of the interpolation calculation < Kriging (3rd) >, see section 2.2.5 (6) of "Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)".)

(7) Calculation of statistical values

With respect to the observed points, located in a mesh of 2.5 × 2.5 degrees, statistical parameters of the values analytically obtained are given including the mean value, maximum, minimum, median (the middle value), mode (the value that occurs most often), and standard deviation.

(For the details of the calculation of statistical values, see section 2.2.5 (7) of "Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3 (NIES-GOSAT-PO-017)".)

(8) Mask Generation

FTS Level 3 processing can estimate values for all the meshes on the globe. However, it may be less reliable when a mesh has few observation points in its vicinity; the estimated values of such meshes must be excluded from data products. Therefore, masking process is conducted for such a mesh that has no FTS Level 2 observation point within the predetermined distance from its center. The length is set to 500km.

6.6.5 TANSO-CAI Level 3 Global Radiance Distribution Processing Algorithm (including cloudy segments)

CAI Level 3 global radiance distribution product is generated using, as an input, CAI Level 1B+ products for three consecutive days. The generated product is recorded in a file by a unit of the whole globe (every three days) in the form of HDF5,. As a result, the image of this product may represent the cloud status of the world.

Fig. 6.6-6 is the processing flow, and the outline of processing follows.

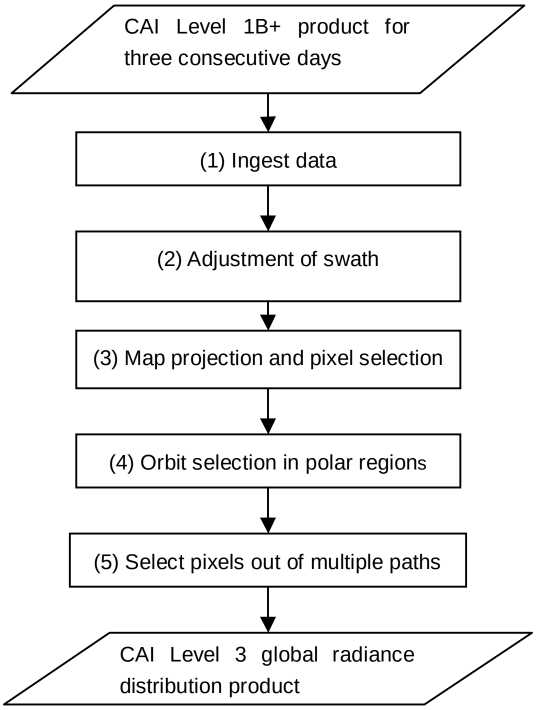


Fig. 6.6-6 Processing flow for TANSO-CAI Level 3 global radiance distribution

(1) Data ingest

Ingest a set of CAI Level 1B+ product data observed in three consecutive days; as GOSAT is on the orbit of three recurrent days, the whole globe is covered in three days. A set of CAI Level 1B+ products is prepared for each of the satellite paths covered by a day.

(2) Adjustment of swath for each band

The swath of CAI band 4 is narrower than those of other three bands. In order to generate a Level 3 product by combining the data of multiple paths, the swaths of all the bands for each path must be the same. Therefore, the data near the edge of the observed swath of band 1 to 3 are cut off to make the widths equal to that of band 4, the narrowest.

(3) Map projection and pixel selection

The global radiance distribution product is generated as a set of data with values for a mesh of 0.125 × 0.125 degrees as projected on an equidistant cylindrical map. As the CAL Level 1B+ products, which is the input of the processing, applies Mercator projection at lower latitude and polar stereo projection at higher latitude, conversion to an equidistant cylindrical projection from either of these two projection shall be performed. In practice, the value of Level 1B+ products, at the location closest to the point (in latitude and longitude) defined by a mesh on the Level 3 product as the central point of the mesh, is stored for the mesh of the Level 3 product.

(4) Orbit selection in a polar region

Only the data of the descending orbit are used because the solar elevation angle of the ascending orbit is lower than that of the descending orbit to bring poor brightness.

(5) Pixel selection out of multiple paths' data

When there are several paths for the central point of a mesh of 0.125 × 0.125 degrees, the pixel value of the most recent observation is adopted to be stored in the file. In other words, the value is overwritten by the latest observation data.

6.6.6 TANSO-CAI Level 3 Global Reflectance Distribution Processing Algorithm (Clear Sky)

CAI Level 1B products for a month are used as input. First, the minimum reflectance in a day is selected in all pixels in each of the mesh of 0.125 × 0.125 degrees. This calculation is repeated for all the days in the month, and the minimum reflectance in the month becomes its output.

The product is stored in a file by a unit of the whole globe (by shifting every three days) in the form of HDF5.

The processing flow is given in Fig. 6.6-7, and the outline of processing follows. As a result, the image of this product looks clear sky.

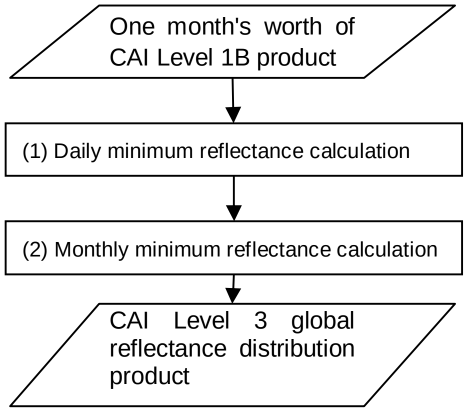


Fig. 6.6-7 Processing flow for TANSO-CAI Level 3 global reflectance distribution (clear sky)

(1) Calculation of daily minimum reflectance

A set of CAI Level 1B products for a whole day is prepared to calculate the least reflectance in the day. For the first step, minimum value of radiance data are extracted from a mesh of given size (0.125 x 0.125 degrees). Then, for the second step, the radiance is converted to the reflectance, This process starts with band 2. If several paths of the day have their pixels in the same mesh, all the pixels of the paths are considered to determine the minimum reflectance.

As for the minimum reflectance of bands 1, 3, and 4, the one corresponding to the same time and position where the band 2 takes the minimum reflectance are adopted as the minimum reflectance of respective bands. The band 2 is given priority because the reflectance of band 2 especially shows a smaller value on a land than the value on a cloud; these characteristics effectively used to remove the cloud.

For the conversion from radiance to reflectance, solar irradiance, solar zenith angle, and the distance between the sun and the earth are taken into account.

Since a mesh in the coastal zone may include land and sea, two kinds of the minimum reflectance are calculated for land and sea. The daily minimum reflectance data for the sea area are made from the CAI pixels located in each of the meshes of 0.125 × 0.125 degrees dimensions, and identified as a sea pixel based on the USGS land-sea flag data (with approximately 1km resolution; seas, lakes, and rivers considered). Similarly, the daily minimum reflectance data for the land area are made from the CAI pixels located in each of the meshes of 0.125 × 0.125 degrees dimensions, and identified as a land pixel based on the USGS land-sea flag data.

(2) Minimum reflectance calculation for a month

a. Prepare daily minimum reflectance data for a specified number of days

Prepare the daily minimum reflectance data for a number of days specified. The files holding the daily minimum reflectance data for the past 30 days including the observation day are specified.

b. Minimum reflectance calculation

The minimum reflectance data are calculated from the 30 days of daily minimum reflectance data starting with the band 2 in the same way as in the calculation of the daily minimum reflectance.

6.6.7 TANSO-CAI Level 3 Global NDVI Processing Algorithm

As the Level 3 global NDVI (Normalized Difference Vegetation Index) data is large in volume, the product is provided by a unit defined as rectangle covering the 1/36 of the surface of the whole globe. Each rectangle is composed of meshes of 15 seconds in latitude and 15 seconds in longitude. Minimum reflectance data of bands 2 and band 3 are calculated every day (approximately 15 paths). Thereafter, minimum reflectance of each mesh is determined using the data accumulated for 15 days; then, the atmospheric correction is applied to the determined minimum reflectance so as to obtain NDVI.

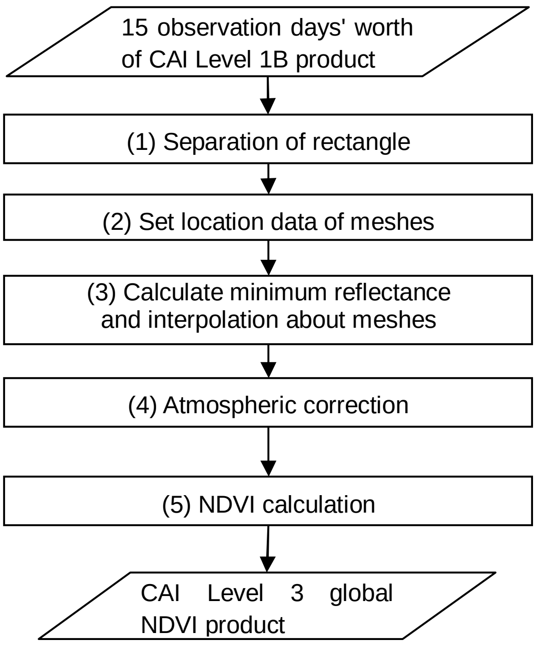


Fig. 6.6-8 Processing flow of TANSO-CAI Level 3 global NDVI

(1) Separation of rectangle

The surface of the globe is divided into 36 rectangles, by 60 degrees longitudinally starting with 25 degrees West, and by 30 degrees in latitudinally starting with 90 degrees North. A number is given to each of the rectangles as shown in Fig. 6.6-9.

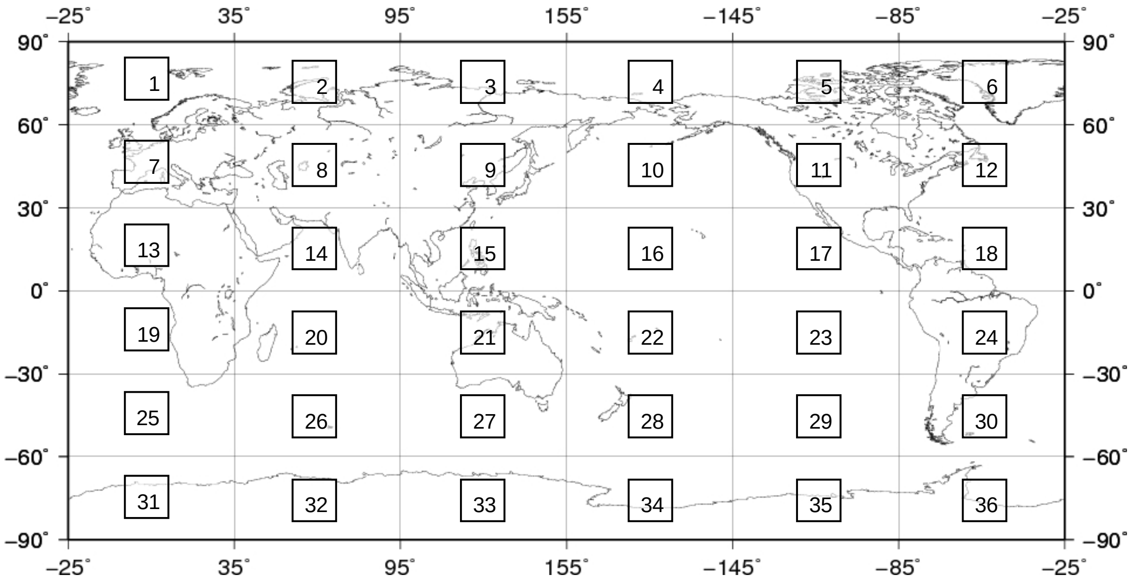


Fig. 6.6-9 Rectangles and rectangle numbers

(2) Set location data of meshes

Each rectangle is composed of meshes having the same angular distance of 15 seconds in both the longitudinal and latitudinal directions. This makes 14,400 of meshes in longitude, and 7,200 of meshes in latitude. The mesh placed at the northwest corner of a rectangle is aligned with the corner lines of the rectangle, and meshes of the same size are placed side by side to fill up the rectangle. Fig. 6.6-10 shows a portion of the northwest corner of rectangle 1.

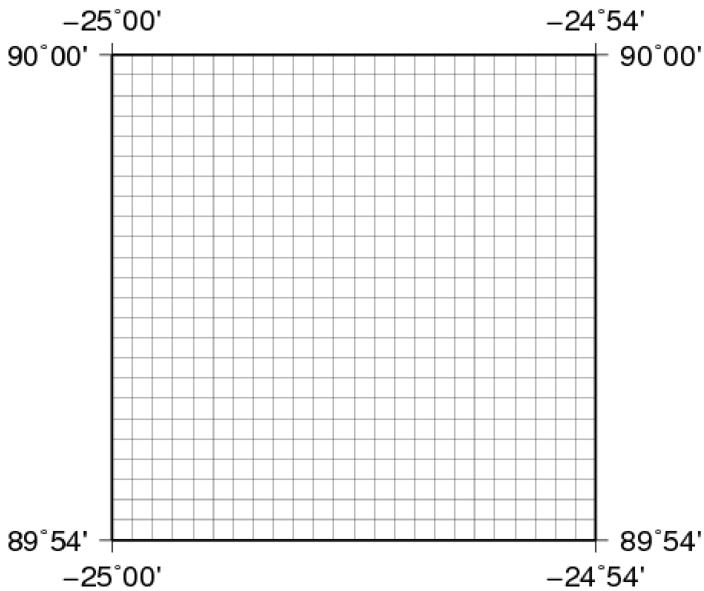


Fig. 6.6-10 Example of meshes placed at the northwest corner of rectangle 1 (the angular distance between meshes is 15 seconds)

(3) Calculate minimum reflectance, and interpolation about meshes

a. Calculate minimum reflectance

1) Get land-sea mask covering the central point of a mesh as defined above by referring to Land-Sea-Mask, which is open to the public by USGS Global Land 1-KM AVHRR Project.

2) Check if each of the meshes is a land area or a sea area. For the sea area, the invalid value is set as a flag; for the meshes regarded as land, the following processing is carried out.

3) Find the mesh in which the central location of a pixel of CAI Level 1B band 2 lies. Then, calculate the reflectance from the radiance of band 2 and band 3 by the equation 6.6-1. As a next step, try to find the minimum reflectance for 15 consecutive days (for five recurrent times.). Provided the mesh is already filled by a reflectance value of band 2, replace it only when the new reflectance value you are going to set is smaller. With this replacement, reflectance data of band 3, solar zenith and azimuth angles, satellite zenith and azimuth angles, ozone concentration[17], and the ground atmospheric pressure are also replaced.

The reflectance is obtained as follows, taking into consideration the distance between the sun and the earth.

[17] If the ozone concentration is not actually measured, a value in the climatological data (300 D.U.) is set.

$$ref = \frac{rad}{irad} \frac{\pi R^2}{\cos(\theta)} \qquad \text{Eq. 6.6-1}$$

R : Distance between the sun and the earth (A.U.)

θ : Zenith angle (rad)

ref : Reflectance

rad : Radiance (W/m^2/µm/sr)

irad : Solar irradiance (W/m^2/µm)

4) If no data are available from the possible 5 trials for a mesh, the invalid value is set to the mesh.
5) The minimum reflectance values for band 3 are selected for the pixel which has the same location as band 2.

b. Interpolation for a mesh

Some meshes will remain with no values after the process mentioned above; i.e. assigning of values of a CAI Level 1B pixel to the mesh in which the center of the pixel is located. This is caused by the fact that the pixel width of Bands 2 and 3 is approximately 500m while the longitudinal distance viewed by an angle of 15 seconds at the equator is approximately 460m. As for the rectangle 1st ~ 6th(north to lat. 60deg.), assign the value of CAI Level 1B pixel, which is in any of 24 meshes next to the blank mesh and has a shortest distance from the mesh as measured between the centers. As for the rectangle 7th ~ 30th, assign the value of Level 1B pixel, which is in any of 8 meshes next to the blank mesh and has a shortest distance from the mesh as measured between the centers. As for the rectangle 31st ~ 36th, invalid value is set.

(4) Atmospheric correction

To save the calculation time, atmospheric correction is conducted at this step for each of the meshes before the calculation of NDVI.

(5) NDVI calculation

a. Calculation method

NDVI for each mesh is calculated by the equation below.

$$NDVI = \frac{ref3 - ref2}{ref3 + ref2} \qquad \text{Eq. 6.6-2}$$

NDVI : Normalized Difference Vegetation Index

*ref*2, *ref*3 : Minimum reflectance of Bands 2 and 3

b. Invalid value setting

If any of the following conditions are satisfied, the invalid value is set to NDVI.

- NDVI is less than - 0.2.
- NDVI is greater than 1.
- Minimum reflectance of Band 2 or Band 3 is negative.
- The sum of minimum reflectance of Bands 2 and 3 is zero.

6.6.8 Level 4 Processing Algorithm

There are two types of Level 4 products, Level 4A and Level 4B. Level 4A product records monthly quantities of carbon dioxide absorption and emission in 64 sub-continental-scale regions (each of which has a size of a few thousand kilometer square) into which the earth is divided. On the other hand, Level 4B product is three-dimensional carbon dioxide concentration distribution which is calculated based on the Level 4A products.

The absorption and emission of the region stored in a Level 4A product are calculated based on the carbon dioxide concentration data of the FTS Level 2 product and of the ground-based observation stations by applying the inverse model analysis. In the inverse model analysis, absorption and emission for a region is estimated through the calculation based on Bayes' theorem. This calculation adjusts the a priori absorption and emission quantities in such a way that carbon dioxide concentration distribution in the atmosphere calculated using the atmospheric transport model converges to the observed values at places where observation has been conducted. The data thus estimated are provided as a Level 4A product to present absorption and emission.

Furthermore, these absorption and emission data are used as input to the atmospheric transport model to calculate the global three-dimensional concentration distribution of carbon dioxide. The carbon dioxide distribution data at typical altitudes ranging from the ground surface to the top of the atmosphere are open to the public as a Level 4B product.

Since the Level 4 processing algorithm is under adjustment as of December 2010, further details are not discussed in this handbook.

6.7 Calibration and Validation

Calibration is performed on Level 1 data, while validation is performed on Level 2 and higher level data. Calibration and validation results are posted up on the NIES GOSAT products distribution website GUIG (GOSAT User Interface Gateway), explained later (refer to section 7.3.1 (4) for the access to the website).

6.7.1 Calibration

6.7.1.1 Outline of Calibration Plan

Calibration is an evaluation process to clarify the characteristics of the sensors and to confirm that the radiometric and geometric accuracies, spectral and image qualities, etc. satisfy the conditions given to their accuracy, and is performed on Level 1 data produced as a standard product. Such evaluations are carried out by characterization in Pre-Flight Test (PFT), on-orbit calibration after the launch using calibration mode data, and vicarious calibration using observation data.
Calibration coefficients are updated to improve the accuracy, and the update is reflected in the improvement of the Level 1 processing algorithm.
Listed below are excerpts from the updates on the processing and parameters.

- FTS
  - Improved SWIR processing algorithm (optimization of the window function for phase correction, delay-match optimization of the gain M data of band 1)
  - Improved TIR processing algorithm (improved the method to select deep-space and/or blackbody calibration data, improved the calibration equations considering the polarization reflectance of the pointing mirror, appended time interpolated calibration data)
  - Refined the spike noise flag
  - Optimized the saturation flag (improved the threshold value for ZPD saturation check, and appended a check for the saturation by low-frequency components)
  - Improved low-frequency correction

- CAI
  - Changed the coefficients of geometric model used in calculation of geolocation (derivation of line-of-sight vector)
  - Vicarious calibration coefficients (have already been applied to the L1B+ and L2 processing)

6.7.1.2 Calibration Schedule

Evaluation of the calibration data was carried out during the initial functional verification operation phase (for the three months after the launch), while evaluation using the observation data was carried out during initial calibration and validation phase (three to six months after the launch). Evaluation results were reflected in the Level 1 products; the Level 1 products after the initial calibration were opened to the public nine months after the launch.

Thereafter, in the normal observation operation, calibration evaluation on and upgrade of the Level 1 products have been carried out regularly, and the data necessary for calibration are acquired in accordance with the normal operation plan. Regarding the frequency of the calibration operation, please refer to chapter 3.

6.7.1.3 Calibration Items

Calibration of TANSO-FTS is performed from three points of view: radiometry, geometry, and spectral characteristics. Summaries of the individual calibration items are described in Table 6.7-1. For the radiance, evaluation method differs from band to band because SWIR measures the radiance of scattered solar light, while TIR measures the radiance of radiation temperature.

TANSO-CAI calibration is carried out from another three points of view: radiometry, geometry, and image quality. Summaries of the individual calibration items are described in Table 6.7-2. For the details of calibration operation, please refer to Chapter 3.

Table 6.7-1 TANSO-FTS calibration items

Evaluation item	Object	Data, time, place, etc.
Radiometric evaluation		
Electrical calibration	Check the electrical calibration data for each band detector, and for each gain setting	PFT data L1 calibration data (electrical calibration)
Solar irradiance calibration	Check the solar irradiance calibration data for each band detector	PFT data L1 calibration data (solar irradiance calibration)
Lunar calibration	Evaluate an absolute amount of radiance from the whole moon surface by pointing to the moon when the average radiance of the moon surface takes its maximum.	PFT data L1 lunar calibration data Still image taken by FTS view monitoring camera
Output in darkness	Evaluate data characteristics in darkness and stability, for each band detector, and for each gain setting. Evaluate temperature dependency	PFT data L1 calibration data (deep-space), etc.
Linearity	Evaluate the data observing an object with uniform radiance; for radiance intensity high and low	PFT data L1 observation data (deep-space, sea, desert, etc.)
Absolute radiometric accuracy (vicarious	Evaluate calibration coefficients and radiometric calibration	PFT data L1 observation data (calibration

Evaluation item	Object	Data, time, place, etc.
calibration)	Calibration using in-situ data (calibration along with a ground surface reflectance measuring experiment) Calibration using global data (calibration using DB, sensors of other satellites, routine observation, etc.) Synchronized observation with other sensors (with a sensor of equivalent wavelength)	site) Calibration experiment data Reflectance DB Data of other satellites
Relative radiance comparison between sensors	Relative evaluation of 1.6µm band (FTS Band 2 and CAI Band 4)	PFT data L1 observation data (FTS, CAI)
Geometric evaluation		
Absolute geometric accuracy. (pointing accuracy)	Evaluate orbit / attitude determination accuracy, long period stability of alignment accuracy (bias and fluctuation component), and resolver precision of pointing mechanism.	PFT data L1 observation data Image taken by FTS view monitoring camera
Orientation stability	Evaluate, during the acquisition of an interferogram, alignment variation, precision of image motion compensation against pointing mechanism, and mirror settlement accuracy.	L1 observation data Image taken by FTS view monitoring camera
Sensor-to-sensor relative registration	Evaluate relative registration between the referential bands of FTS and CAI when the simultaneous observations are conducted.	PFT data L1 observation data (FTS, CAI) Image taken by FTS view monitoring camera
Band-to-band registration (for reference)	Evaluate relative registration between FTS reference band and each of the other bands	PFT data
Spectral characteristics evaluation		
Instrument line function	Evaluate 1.55µm wavelength laser output (band 2)	PFT data L1 calibration data
Wavelength calibration	Evaluate the spectral positions of known atmospheric absorption lines	PFT data L1 calibration data L1 observation data
Polarization sensitivity	Evaluate, for each band, observation data of a target whose polarization characteristics are known.	PFT data L1 calibration data (solar irradiance calibration)
Wavelength stability	Evaluate sampling jitter, and temperature dependency (especially the relation with the monitoring temperature of 1.31µm sampling laser)	PFT data L1 calibration data L1 observation data
SNR	Evaluate observation data of a uniform object for each band detector, and for each gain setting Evaluate temperature dependency.	PFT data L1 observation data (desert, etc.)

Table 6.7-2 TANSO-CAI calibration items

Evaluation item	Object	Data, time, place, etc.
Radiometric evaluation		
Electrical calibration	Check electrical calibration data for each band detector, and for each gain setting	PFT data L1 calibration data (electrical calibration)
Lunar calibration	Evaluate an absolute amount of radiance from the whole moon surface by pointing to the moon when the average radiance of the moon surface takes its maximum.	PFT data L1 lunar calibration data
Offset	Evaluate optical black output characteristics, characteristics in darkness, and stability for each band detector, and for each gain setting. Evaluate temperature dependency.	PFT data L1 calibration data (nighttime) L1 observation data (band 4 optically black element)
Linearity	Evaluate the data observing an object with uniform radiance; for radiance intensity high and low.	PFT data L1 observation data (nighttime, sea, desert, etc.)
Absolute radiometric accuracy (vicarious calibration)	Evaluate calibration coefficients and radiometric calibration Vicarious calibration experiment (ground surface reflectance measurement)	PFT data L1 observation data Experiment data Reflectance DB

Evaluation item	Object	Data, time, place, etc.
	Calibration using global observations and DBs (use AERONET, SKYNET, and reflectance DB) Synchronized observation with other sensors (with a sensor of equivalent wavelength)	
Relative radiance comparison between sensors	Evaluate relative radiance of 1.6μm band (CAI band 4 and FTS band 2)	PFT data L1 observation data (CAI, FTS)
Geometric evaluation		
Absolute geometric accuracy. (pointing accuracy)	Evaluate orbit / attitude determination accuracy, long period stability of alignment accuracy (bias and fluctuation component).	PFT data L1 observation data
Band-to-band relative registration	Evaluate relative registration between CAI reference band and each of the other bands	PFT data L1 observation data
Sensor-to-sensor relative registration	Evaluate relative registration between the referential bands of CAI and FTS when the simultaneous observations are conducted.	PFT data L1 observation data (CAI, FTS) Image taken by FTS view monitoring camera
Image quality evaluation		
Sensitivity calibration among pixels	Remove stripe noise	PFT data L1 observation data (desert, etc.)
MTF (for reference)	Evaluate the modulation transfer function about the image after geometric correction for each band detector, and for each gain setting • Line image distribution function (edge spectrum) • Point image distribution function (point spectrum)	PFT data L1 observation data (coastline, island, etc.)
SNR	Evaluate observation data of a uniform object for each band detector, and for each gain setting Evaluate temperature dependency.	PFT data L1 observation data (desert, etc.)

6.7.2 Validation

6.7.2.1 Summary of Validation Plan

"Validation" for GOSAT products is to evaluate uncertainty (bias, variation, etc.) in the Level 2 products by referring to data more reliable and acquired independently of the GOSAT products. The validation is carried out using the data acquired by ground observation, air-borne observation, and so on. The concept of validation is illustrated in Fig. 6.7-1.

Regarding the validation of Level 3 and Level 4 products, confirmation of the calculation process and comparison with other data are carried out.

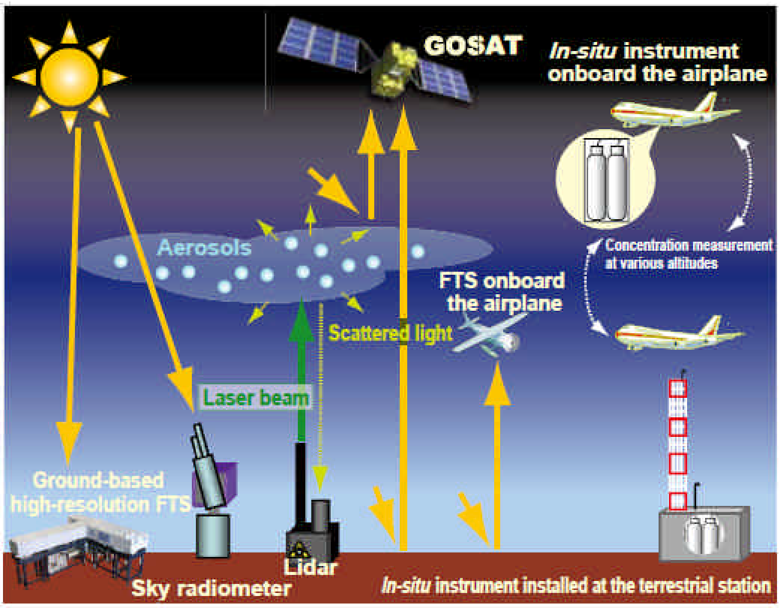


Fig. 6.7-1 Schematic diagram of GOSAT products validation

While the validation is intended for the quality evaluation of GOSAT products, it also help evaluate the validity of data processing algorithm. If something uncertain were found not negligible, the causes are clarified through investigation to improve the algorithm and the like as necessary.

Considering that the Level 3 and Level 4 products shall be estimated using the Level 2 products, adopted models, and so forth, the evaluation of Level 2 products has vital importance. Accordingly, priority is given to validation activities in the order as follows.

(1) Level 2 SWIR CO_2 column amount, and Level 2 SWIR CH_4 column amount
(2) Level 2 TIR CO_2 profile, and Level 2 TIR CH_4 profile
(3) Level 3 SWIR global CO_2 distribution, and Level 3 SWIR global CH_4 distribution
(4) Level 4A global CO_2 flux
(5) Level 4B global CO_2 distribution

For validation, it is preferable to use a variety of observation data, which are routinely acquired across the world. Furthermore, a plurality of specific observation points are selected to organize a super-site (a site installed with observation equipment necessary for validation, and focused on the continual observations) for the validation. In addition, campaign observations are carried out including an air-borne observation under various meteorological conditions.

The data to be validated are those which shall be obtained under the following geographical and meteorological conditions. Note that locations covered with thick clouds are not in the scope of validation.

- Land area with clear sky
- Sea area with clear sky (sunglint observation)
- Land area with thin cirrus clouds and aerosols
- Sea area with thin cirrus clouds and aerosols (sunglint observation)

The validation results on the processing of version V01.xx are posted on GUIG; so please refer to the website as desired.

6.7.2.2 Observation Experiments for Algorithm Validation

The processing algorithm to calculate the FTS Level 2 CO_2 column amount is validated through experiments simulating the satellite observation. Such experiments are conducted by observing the sunlight reflection from the earth surface with a Fourier transform spectrometer (similar to the sensor on board the satellite) installed at a high-elevation ground point or on board an airplane. Brief explanations follow about the experiments.

(1) Observation at a high elevation on the ground

An experiment is carried out using a Fourier transform spectrometer (hereinafter called the spectrometer) which is similar to TANSO-FTS; the spectrometer is set at places including a mountain top. In order to validate the CO_2 concentration calculated from the observed results of the spectrometer, an air plane equipped with a CO_2 concentration meter is flied gradually increasing its altitude to measure the CO_2 concentration directly. Then the measured data are compared with the data derived from the spectrometer.

The experiments carried out in the year of 2005 and 2006 near the top of Mt. Tsukuba (800m) have demonstrated that the CO_2 column amount, in the atmospheric layers with an altitude of 3km or lower, is well observed by the spectrometer with an accuracy of approximately 1%.

(2) Air-borne observation

The spectrometer and a CO_2 concentration meter are installed on board an airplane that flies in the sky at a high altitude, and the data observed by the spectrometer and the data measured by the CO_2 concentration meter are compared so as to validate the processing algorithm. This method of validation has an advantage compared to the fixed point observation done at a high-elevation ground point because the observation from an airplane will be conducted, similar to the case of a satellite, with a downward view, although the vibration of aircraft remains as a problem.

(3) Campaign observation

Synchronized to an observation from the satellite, CO_2 column amount is calculated with high accuracy from the CO_2 concentration measured directly by an airplane able to reach a high altitude; then evaluation is done to see if there may exist any secular change with the precision of instruments. Aerosol, which acts as an error factor, is also measured directly.

The CO_2 concentration above the altitude an aircraft can reach varies with the altitude of the tropopause. Therefore, it is essential to know the altitude of the tropopause precisely; observation data simultaneously taken by a rawinsonde, the objective analysis data, etc. are used for this purpose.

Regarding the CO_2 concentration near the ground, lower than the altitude an airplane may fly along, the concentration value measured on the ground surface is extrapolated.

6.7.2.3　Validation of TANSO-FTS SWIR Products

(1) Validation of CO_2 and CH_4 column amounts observed by SWIR

The instrument to be used in the observations for the validation of CO_2 and CH_4 column amounts must have an accuracy of approximately 1% or better, with no biases; and the instrument must be the one developed based on the fully established techniques to present highly reliable quality of data. As a means to observe a column amount in a straight-forward way, the absorption method that makes use of direct sunlight as a light source is the best method, and a high resolution FTS, installed on the ground, is the most appropriate instrument in the measuring instruments available at present. The FTS will complete an observation anytime in about 10 minutes as long as direct beams of sunlight are kept comings.

The data collection policy for the validation data is as follows.

- Install instruments (high-resolution FTS, lidar, and sky radiometer) for observation at a plurality of specific observation points to perform observations intensively at these super-sites.
- For the validation of data observed outside the support of super-sites, campaign observations including aircraft may effectively cover the ground areas having

rough terrain and/or under bad meteorological conditions.

- To cover the whole globe observed by GOSAT, the observation data routinely acquired are utilized, such as data taken by an existing high-resolution FTS installed on the ground, air-borne observation data, and ground observation data (from WDCGG (World Data Center for Greenhouse Gases) of WMO (World Meteorological Organization)).
- On the sea, the column amount is obtained from a sunglint observation. As the concentration variation is rather small on the sea compared to the land, the data of a land validation site in coastal areas can be used with wind direction considered. In addition, observation data acquired on islands and by vessels can also be used for indirect evaluation.

Based on the policies above, validation data are acquired for typical observation points; while the observation points actually used are selected following the criteria listed below.

- Latitude : low , middle , high
- Amount of water vapor : large, small
- Albedo : uniform, non-uniform
- Aerosols : variant, invariant

At present, 10 observation points equipped with FTS, and another 10 points observed by an aircraft, are supposed to be enough for validation to satisfy the minimum requirements. However, if a handy instrument for the validation observation satisfying the validation requirements becomes available, a larger number of observation points will be selected extensively for validation.

The data acquired for each observation point are evaluated with spatial variations and temporal fluctuations being considered so as to clarify the uncertainties the products may have. However, in order to evaluate bias components, roughly three months of observations shall be repeated at the place where seasonal variation is rather small, while six months of observations are required in general. Quality assurance is given, based on evaluation thus conducted, to a set of products grouped by the criteria listed above. If this way of evaluation is considered difficult to apply, such alternative method may effectively work as a trajectory analysis with temporal and spatial variations, and/or a validation and analysis based on the regional CO_2 transport model.

Concrete plans for observation and validation data acquisition are as follows.

a. Validation by FTS observation

1) Observation by ground-based high resolution FTS

Conduct routine observations using a ground-based high-resolution FTS at a plurality of observation points in Japan. In the validation, it will be useful to make an evaluation by analyzing the FTS observation data using the processing algorithm of TANSO-FTS (radiative transfer equation).

2) Utilization of the data of ground-based high resolution FTS networks and the like

The data of ground-based high resolution FTS observation networks shall be used. The GOSAT operations team of JAXA will arrange the usage of these data through direct negotiation with the pertinent data providers, RA-based research cooperation, and so forth.

For the sites to acquire the validation data, considering that the footprint of TANSO-FTS is rather wide to be 10.5km, a place flat and uniform to that extent of FTS footprint is preferable. Such places will not involve many factors to cause errors, and suitable for a validation observation point at the initial stage. Accordingly, the validation sites are selected based on the following conditions.

- Seasonal variation: start with little variation (the Southern hemisphere), then to larger ones (the Northern hemisphere)
- Air pollution: start with little pollution, then toward serious places
- Land surface: start with simpler shape, then to more complex one

The options are:

- Sunglint
- Snow and ice

3) Observation by smaller FTS

Provided mobile observations are necessary, small-sized FTS instruments will be used after the evaluation of data quality as accuracy, and operational stability.

b. Validation by air-borne / balloon-borne observation

1) Utilization of data from the air-borne observations

A CO_2 concentration measuring equipment on board an aircraft observes data continuously to acquire not only the spatial (horizontal) distribution of CO_2

concentration at very high altitudes, when the aircraft flies horizontally, but also the CO_2 concentration profile around the airport as the aircraft ascends from or descends to the airport..

However, at ascending from an airport, an aircraft moves horizontally about 100km before it reaches up to the altitude of about 10km where it flies horizontally, and at descending from the cruising altitude of 10km, it moves 200 to 300km before landing on the ground; therefore, such spatial difference must be considered to make the use of the observed data for analysis. Atmospheric tracer transport model can be applied to the analysis. Furthermore, since the concentration in the lower atmosphere near an airport tends to rise under the influence of the urban air in many cases, wind direction must be considered to make the use of data effectively. Moreover, the fluctuation of the CO_2 concentration in the layers above the highest altitude that an aircraft can reach must also be evaluated. So far, the findings from balloon-borne observation of the stratosphere have revealed that the fluctuation of the column amount is within 0.5% when roughly estimated. Further details will be investigated in the continued studies.

2) Data acquisition by balloons

Balloon-borne observation data, including the past data, must be obtained in order to ascertain the characteristics of the variation of the CO_2 column amount in the layers above the upper limit of air-borne observation.

c. Miscellanies

1) Observation by small balloons

The CO_2 sonde installed on board a small-sized balloon is under development, which will be used for the validation after evaluating its data quality such as measurement accuracy, operational stability, etc., and ensuring that it is practical in terms of cost and the like.

2) Observation by compact spectrometer

The Fabry-Perot Etalons based spectrometer is under development, which will be used for the validation after evaluating its data quality such as measurement accuracy, operational stability, etc., and ensuring that it is practical in terms of cost and the like.

(2) Comparison in the global distribution of CO_2 and CH_4 column amounts based on SWIR observation

The calculation proceedings of the L3 processing led by statistical algorithm shall be confirmed. It should be noted that the L3 products do not require dedicated evaluation means because they are derived from the validated L2 products through statistical calculations taking averages spatially and temporally.

(3) Comparison of CO_2 flux

A Level 4A product presents estimated monthly average of CO_2 flux for a region as defined by dividing the whole surface of the globe into 64 regions.

The data observed by ships are useful to compare with the data presented by Level 4A products because the flux is supposed to be nearly uniform on the sea about an area of latitude 5°x longitude 5°.

As for the flux on the land, the flux distribution is calculated per mesh of 1°latitude x 1°longitude with a distribution pattern initially assumed for the region mentioned above. However, it is difficult to use observed values of CO_2 flux for the validation of Level 4A products of the land because observation of CO_2 flux can be done only on a limited number of points while the flux varies much depending on a district, and on a location. To cope with the issue thus identified, a scale-up procedure using the land ecosystem model is required. The scale-up procedure has been investigated in a number of countries including Japan.

(4) Comparison of the global distribution of CO_2 concentration

The product to be distributed as a Level 4B product is a monthly average of three-dimensional concentration distribution in a mesh of latitude 1° × longitude 1°. The comparison of a Level 4B product with other observation data is made using a one-hour value or monthly average value of a latitude 1°× longitude 1° mesh, which is the base data of the Level 4B products. As the data for comparison, the data used in the Level 2 validation (column amount acquired by a ground-based FTS or the like, concentration profile acquired by air-borne observation), the data acquired by other kinds of ground and marine observations, and so on, are comprehensively utilized.

(5) Comparison with other satellites

Comparison with other satellites that observe CO_2 and CH_4 column amounts is useful for the evaluation of data quality of the GOSAT products. A typical example is SCIMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric

CHartgraphY) on board the environment observation satellite Envisat .

6.7.2.4 Validation of Parameters Related to SWIR Observation Error Factors

As parameters to cause errors in SWIR observations, what follows are being considered.

(1) Aerosols and thin cirrus clouds

In order to evaluate the appropriateness of the Level 2 processing algorithm for TANSO-FTS (SWIR) data, in addition to the validation of the product data quality, the parameters related to error factors, namely the optical characteristics of aerosols (such as optical thickness, wavelength index, and single scattering albedo), height profiles, etc. are used for the evaluation.

Furthermore, it is necessary to install sky radiometers and lidars at the locations where ground-based FTS or air-borne observation is carried out. The lidar can measure the vertical distribution of aerosols and thin cirrus clouds with an accuracy of approximately 15m, and distinguish sphericity from non-sphericity by checking the degree of extinction of polarization, thereby identifying the substance as rain cloud, cirrus cloud, or sand dust. The sky radiometer measures the direct sunlight and the forward scattering in the sky. The measurements can also be used for determining not only the optical thickness, particle size distribution, and complex refractive index, but also the primary scattering albedo and phase function. These data are planned to be used for the validation of TANSO-CAI products.

(2) Ground surface reflectance

The data acquired by MODIS and ASTER, of the area having homogeneous ground surface characteristics in particular, shall be used to check the accuracy of the ground surface reflectance calculated as a result of the SWIR retrieval operation.

(3) Oxygen column amount

The oxygen column amount, acquired from Band 1 (O_2 A-band), shall be validated.

a. Ground atmospheric pressure and rawinsonde data

Observation will be performed, as necessary, to make use of the aerological observation data routinely taken. The rawinsonde data may also be used for the validation of other physical quantities.

b. Objective analysis data

Objective analysis data shall be used for the validation in order to complement the aerological observation data, which are not provided so uniformly over the globe; they are rather sparse above the ocean, polar regions, and developing countries.

6.7.2.5 Validation of TANSO-FTS Products

The data acquired for the validation of SWIR CO_2 and SWIR CH_4 products are also used for the validation of Level 2 TIR CO_2 and Level 2 TIR CH_4 products. The validation will be conducted more effectively when the profiles of temperature, atmospheric pressure, and humidity, and the infrared radiation rate are also considered. Regarding the nighttime data acquired, they will be utilized as much as possible.

6.7.2.6 Validation of TANSO-CAI Products

CAI measures such parameters as cloud coverage and aerosol amounts, which will cause errors in the data of FTS products. Before generating an FTS Level 2 product, cloud information on the sight line the sensor observes shall be checked to see whether or not the observed FTS data are of effective use. This is done by referring to CAI Level 2 cloud flag products. Accordingly, the validation of the CAI Level 2 cloud flag product has been performed.

The validation results have clarified that the algorithm, used for the calculation of the CAI Level 2 cloud flag product, has no serious problem and gives reasonable cloud coverage in most cases except for the polar regions and sunglint areas; the validation is done by comparing visually the cloud flags with the original CAI images.

Cloud coverage conditions at the FTS footprints can be confirmed by referring to FTS browse data. The FTS browse data are generated from CAI observation data. Fig. 6.7-2 shows an example of FTS browse data; the red circle signifies the view range of FTS, the green arrow shows the direction GOSAT travels, and the orange arrow shows the direction the sun lies.

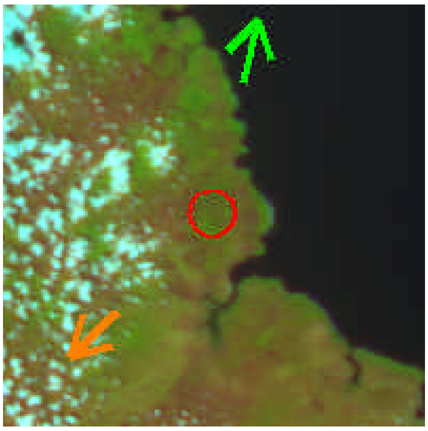


Fig. 6.7-2 Example of browse data

Chapter 7　GOSAT Data Product Distribution

7.1　Data Storage

NIES GOSAT DHF stores and administers data products of Level 1 or higher for users. The total data volume for the five years of GOSAT mission is estimated to amount as much as 400TB including the data for validation and for reference such as meteorological ones.

7.2　Data Product Distribution Policy

7.2.1　Data Policy

(1) Background

a. The GOSAT data will be distributed on the “non-discriminatory” basis as provided for in the Principles Relating to Remote Sensing of the Earth from Space issued by the United Nations.

b. The GOSAT data will be processed in a prompt manner with the help from inside and outside Japan and will be provided at large, thereby promoting the use of the GOSAT data.

c. The GOSAT Data Policy refers to how to utilize the GOSAT data to be obtained after the launch, with a view to the evolution of research and development into the future, while maintaining the balance between international cooperation and national interests.

d. The GOSAT Data Policy takes into consideration the following missions of Japan Aerospace Exploration Agency (hereinafter referred to as “JAXA”), National Institute for Environmental Studies (NIES), and Ministry of the Environment of Japan (MOE) (hereafter collectively called as the “Three Parties”), to the maximum extent possible.

1) JAXA, as a space agency, promotes the use of the GOSAT data inside and outside of Japan by providing all GOSAT data users with the data in a substantial quantity in a prompt manner, for best results of the Project.

2) NIES, as an institute for the sciences, promotes the use of the GOSAT data especially in scientific fields by distributing reliable data products to the users upon carefully evaluating the data quality, for best results of the Project.

3) MOE will use the GOSAT data in its environmental administration through the data use inside and outside of Japan for scientific purposes and consequently the minimizing of uncertainties with respect to global warming, while maintaining the balance between international cooperation and national interests.

(2) Policies on when to start the distribution

a. The data distribution to all users will start immediately after the completion of the calibration and validation work.

b. The data will be provided with priority to internal users, research investigators or research organizations approved by research announcement activities (RA users), the members of the Science Team, and Alliance Organizations, which are collaborating in the aspects of sensor development, scientific research, data processing, and necessary data distribution, earlier than the other users, in cases where such data distribution is necessary for data processing tasks in terms of calibration, validation, etc. and where such data distribution contributes to the development of the GOSAT sensor or the research on utilization of the GOSAT data.

(3) How to distribute the GOSAT data

Data users shall conclude an arrangement with JAXA or NIES in the forms of agreement, contract, agreeing to the terms and conditions online, etc. before receiving data products on line, in principle, in accordance with the stipulations set forth in Article 14 hereunder.

When a large number of data products are to be provided, there will be a possibility that JAXA or NIES may provide the data through a private data distributer selected by JAXA or NIES.

(4) Pricing of GOSAT data products

a. For research purposes in the fields of earth observing system development and Earth science Users will be charged actual expenses necessary for reproduction of the data, etc. In case of on-line distribution, however, the data will be provided free of charge.

Incidentally, a limited number of products will be distributed for free for the purposes of promotion and education that contribute to the activities of the Three Parties.

b. For purposes other than those that fall under (a) above (commercial purposes) Users will be charged, in addition to actual expenses necessary for reproduction of the data, etc., usage fees in accordance with the number of products provided.

(5) Rights associated with the GOSAT data

a. The Three Parties shall own all intellectual property rights including but not limited to copyrights in relation to all the data they provide.

b. When a user has generated a higher-level, value-added data product[18], the Three Parties shall not exercise their copyrights, i.e., rights as the copyright holders of the original data, to the derivative data and the user may use the value-added data based on his/her own copyrights as the developer of the data. However, a certain payment shall be collected as a license fee or the like for a commercial use of such a product, as described in (4) b. above.

(6) Terms and conditions concerning the use of the GOSAT data

a. The use of the data for any purpose in opposition to peaceful use is prohibited.

b. The use of the data for any other purpose than the user's purpose of data use is prohibited.

c. Redistribution of the data to any third party is prohibited. (The data distributors who have signed a data distribution agreement with JAXA or NIES may redistribute the data to third parties, but the third parties who obtained the GOSAT data from such a data distributor are prohibited to redistribute the data to any third party.)

d. Any publication of outcomes obtained in consequence of the use of the data must be accompanied by any of the following indications.

- ©JAXA/NIES/MOE
- Copyright: JAXA/NIES/MOE
- @Japan Aerospace Exploration Agency / National Institute for Environmental Studies / Ministry of the Environment
- Copyright: Japan Aerospace Exploration Agency / National Institute for Environmental Studies / Ministry of the Environment

Incidentally, the user is also required to indicate that the original data are provided by JAXA/NIES/MOE, if he or she has generated higher-level, value-added data and wishes to provide a third party with the value-added data or publish them.

e. Use of the GOSAT data and/or higher-level, value-added data under the mechanisms of the Kyoto Protocol, namely the Joint Implementation (Article 6 thereof), Clean Development Mechanism (Article 12 thereof), and the International Emissions Trading (Article 17 thereof), is prohibited without consent of the Three Parties. Any use for such a purpose may be allowed if the PI obtains an approval of and concludes a contract with the Three Parties in advance.

f. Users who obtain the GOSAT data for the purpose of earth observing system

[18] High-level, value-added products are, of modified products, those that have been modified by applying high-level data processing and which are irreversible to the original data. High-level data processing here includes data analyses or a combination of satellite data acquired by different missions, image processing based on external information other than the original data, conversion to physical quantities, and so forth.

development and geoscience research are required to report on or publish their research results. In a case where a user wishes to publish his/her outcomes from the use of the data from three (3) to nine (9) months after the launch, he or she is required to send a copy of the outcomes to the Three Parties.

g. The Three Parties shall not be liable for any missing data, degradation of data quality, delay in data delivery, or any other situation in which the data cannot be provided, as a result of problems that occur to the spacecraft or the ground facilities.

(7) Handling of the personal information

JAXA and NIES shall not exchange the personal information of their users with each other. If necessary, JAXA or NIES will inform the other of statistical information on the types of users and products with regard to the data provided.

7.2.2 User Category

Table 7.2-1 shows the categories of GOSAT data user.

Table 7.2-1 User Categories

User Category	Description
Project Staff (PS)	Researchers, scientists, staff members, etc. who belong to the GOSAT Project implementation body (Three Parties) and engage in the GOSAT Project or those who belong to other organizations but engage in the GOSAT Project as contractors to the Three Parties.
RA Investigator (RA)	PI and CI[19] approved and registered by the Three Parties.
RA* Investigator (RA*)	An RA Investigator who is engaged in a research theme in the algorithm or calibration/validation fields and is approved and registered by the Three Parties.
Science Team Member (ST)	A member of the GOSAT Science Team organized by the Three Parties. (Includes leaders and sub-leaders of working groups.)

[19] PI stands for Principal Investigator representing a research theme approved by the Three Parties as a result of the RA selection. CI stands for Co-investigator participating in a research theme approved by the Three Parties as a result of the RA selection.

User Category	Description
Science Team Member* (ST*)	A member of the GOSAT Science Team who is engaged in a research theme in the algorithm or calibration/validation fields and is approved and registered by the Three Parties.
Alliance Organizations1 (sensor development, research, data processing, provision of necessary data) (AO1)	An organization which has signed a cooperative agreement with the Three Parties concerning the collaboration in the aspect of sensor development, research, and data processing or provision of data necessary for GOSAT data processing. Note that an investigator[20], contracted by an AO1 solely for the purpose of carrying out the above-mentioned activities and recognized by the Three Parties as such, is regarded as a member of the AO1.
Alliance Organizations1* (research on algorithms, calibration and validation) (AO1*)	Of AO1s, an organization which has signed a cooperative agreement with the Three Parties for the collaboration in the aspect of research on algorithm, calibration, or validation.
Alliance Organizations2 (data distribution) (AO2)	An organization which has signed a cooperative agreement with the Three Parties for the collaboration in the aspect of distribution of GOSAT data.
General User (GU)	All data users other than the above-defined users.

Product types available for users depend upon the category. Please refer to section 6.2 for details.

7.2.3 Processing Version of a Product

Processing algorithm is modified based on calibration and/or verification results. Any modification accompanies the version change of GOSAT product processor and/or processing parameter. Major or minor version is changed depending on the kind and scale of changes in the processor algorithm.
GUIG, a graphical web interface for GOSAT product distribution explained later in section 7.3, provides information about "Difference of the Standard Product by version" and "Relationship between obs. period and version". There may exist

[20] An investigator here may include a user of higher-level data processed by an AO1.

products of different versions for a same day because data of the past are reprocessed in a batch by a processor of a new version. Therefore GUIG users are expected to have this in mind when he/she specifies a processing version in the search of GOSAT data.

GOSAT products have a file name as defined to include the processing version to distinguish themselves. Refer to section 6.3 for the details of file name definition.

The sections to follow describe the versions of standard products being available for general users.

7.2.3.1 Versions of TANSO-FTS Level 1B products

The version for TANSO-FTS Level 1B product is defined as follows.

[AAAPPP]

AAA : Algorithm version

PPP : Parameter Version

The first digit of AAA or PPP stands for major version, while the second and the third digits represent minor version.

7.2.3.2 Versions of TANSO-CAI Level 1B, 1B+, and higher level products

The version for TANSO-CAI Level 1B, 1B+, and higher level product is defined as follows.

[VMM.NN]

V : Fixed

MM : Major version

NN : Minor version

7.2.4 Calibration stages and validation stages

Standard products are provided at different stages in accordance with the progress of calibration, validation and comparison. There are four calibration stages for Level 1 standard products, four validation stages for Level 2, and three validation stages for Level 3 standard products. Each stage of calibration and validation is defined in Table 7.2-2 through Table 7.2-4, respectively. (As for Level 4 products, stages have been defined yet.) As for the Research and Internal products, there is no such stage to be defined.

Table 7.2-2　Definitions of the calibration stages for Level 1 standard products

Calibration stage	Definition
Unchecked (U)	Products generated by simply processing the observation data.
Preliminarily checked(P)	Products visually checked and taken as reliable.
Calibrated (Ca)	Products made after the initial sensor calibration activity and taken as reasonable.
Confirmed (C)	Calibrated products having been used by a limited number of users for a certain period of time and the problems reported by the users already fixed, if any.

Table 7.2-3　Definitions of the validation stages for Level 2 standard products

Validation stage	Definition
Unchecked (U)	Products simply made from Level 1.
Preliminarily Validated (P)	Products made from Level 1 and taken as reliable after a visual check.
Validated (V)	Products taken as reasonable through the comparison with such verification data as the ones observed on the ground.
Confirmed (C)	Validated products having been used by a limited number of users for a certain period of time and the problems reported by the users already fixed, if any.

Table 7.2-4　Definitions of the validation stages for Level 3 standard products

Validation stage	Definition
Unchecked (U)	Products generated by simply processing Level 1 data or Level 2 data.
Evaluated (E)	Products regarded reliable as made by processing Level 1 or Level 2 data.
Confirmed (C)	Evaluated products having been used by a limited number of users for a certain period of time with no problems reported.

7.2.5 Purpose of data use

The purposes of using the GOSAT data are categorized as follows:

(1) Development of Earth observing systems and Earth science researches (non-commercial use) including:

a. Technical development

Evaluation of the spacecraft and sensors to help develop the Earth observation technology, enhancement of analysis techniques, and contribution to next-generation Earth observing satellites and ground systems.

b. Research on and demonstration of exploitation of the data

Research on and demonstration of exploitation of the data in the Earth environmental studies.

c. Research on Earth science, etc.

Research which will contribute to the development of Earth science and to the solution to global environmental issues, by clarifying Earth environment change mechanisms, etc.

d. Other purposes that are relevant to the activities of JAXA, NIES, and MOE

Use of the data contributing to the activities of the Three Parties, such as public relations and educational activity for the spread and enlightenment of the schemes of Three Parties.

(2) Other purposes than those described in item (1) above (commercial use)

7.3 How to search and get GOSAT data products

Researchers whose research subject is officially adopted, researchers of Alliance Organizations, and general users will order GOSAT data via GUIG. Explanations below are for general users.

GUIG is served from the top page of “GOSAT Project” (see Fig. 7.3-1). “GOSAT Project” also provides up-to-date information about GOSAT, Technical Information, and Project Results. The URL is shown below.

GOSAT project http://www.gosat.nies.go.jp/index_e.html

By clicking the portion circled red as shown in Fig. 7.3-1, you are introduced to GUIG (see Fig. 7.3-2).

You can search GOSAT data and order them from GUIG. You may get such technical information as GOSAT product specifications as well.

One click leads you to GUIG.

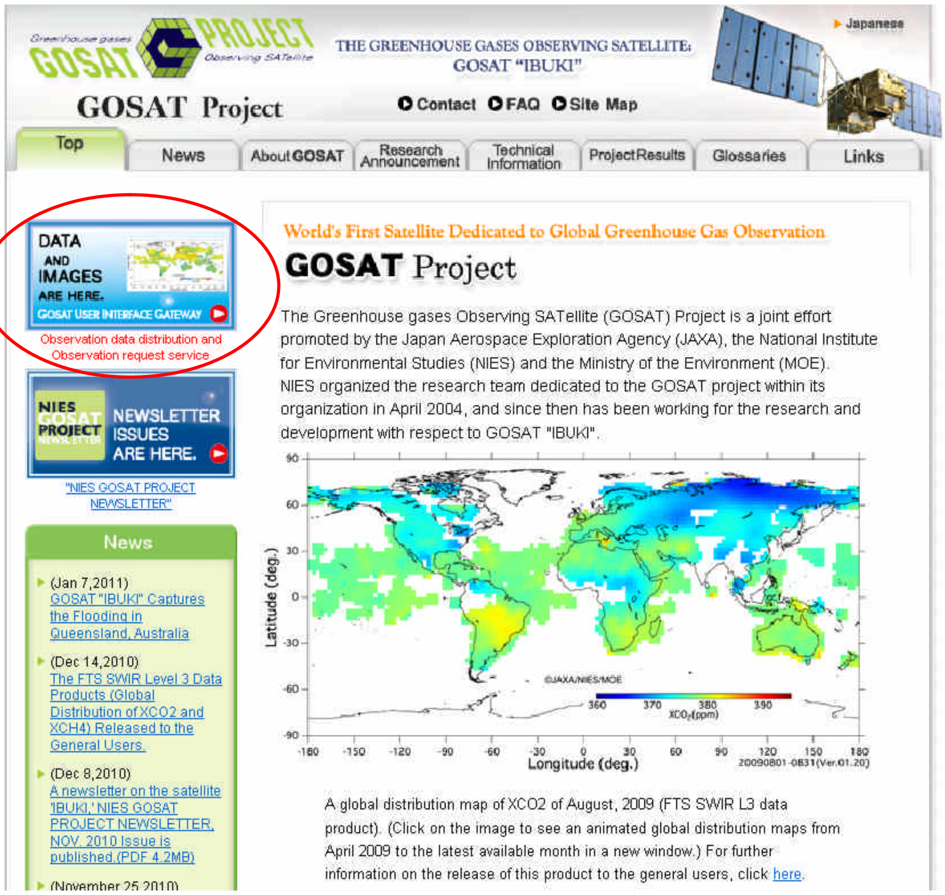


Fig. 7.3-1 Website of GOSAT Project

Fig. 7.3-2 GUIG top page

7.3.1 GUIG Functional Summary

(1) Managing user information

Let users register or change their information. User password may be reissued. These services are made on the user authentication window as shown in Fig. 7.3-3.

(2) Searching and ordering GOSAT data products

Let users specify conditions to search products from the GOSAT database. Users may order any of the products thus searched.

These services are available from the Selection Menu window shown in Fig. 7.3-4 by selecting “L1 and L2 Product Search and Order” or “L3 and L4 Product Search and Order”.

(3) Downloading the ordered data products

Let users download the data product ordered. This service is available from the Selection Menu window shown in Fig. 7.3-4 by selecting “Product Download”.

(4) Providing Information

Give users such information as GOSAT product specifications, algorithm to generate the products, and GOSAT path calendar. This service is available from the Selection Menu window shown in Fig. 7.3-4 by selecting “Documents” or “Observational Information”. Most of the documents referred to in this document are available from the site.

Information available as of December, 2010 includes:

a. Document (downloadable by GUIG)

1) ATBD (Algorithm Theoretical Basis Documents), Product Format Descriptions, Product Description, Results of Validation,
2) Difference of the Standard Product by version
3) Products list under distribution, Relationship between observational period and version
4) Remarks on monthly FTS SWIR Level 2 Product

b. Observational Information (shown on GUIG web pages)

1) Path Calendar
2) Observational Schedule
3) SWIR L2 Global Distribution Map

Guest users are also able to access the documents and information listed above.

Fig. 7.3-3 User authentication window

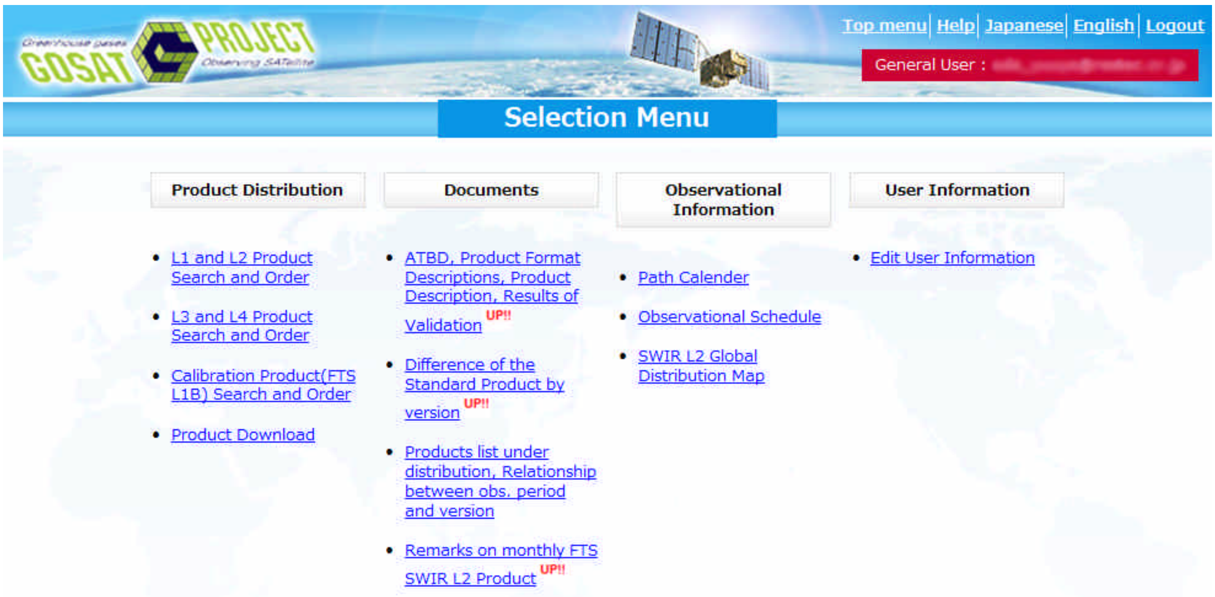


Fig. 7.3-4 Selection Menu window

(Shows up when you via User authentication window shown in Fig. 7.3-3)

7.3.2 Searching, ordering, and getting GOSAT data products

Fig. 7.3-5 is a flow you have to follow when you get GOSAT data products. In order to specify the data you order, some search operation must precede. Input search conditions such as a product type, observation dates of your concern, and an observed area of interest (AOI) then select from the searched results what you have to order. You may take another way of searching if you know the observation IDs of your interest. Just specify the IDs then GUIG will lead you to the next step.

A user who has logged in as a guest may also search the product data although he/she will not be able to order them.

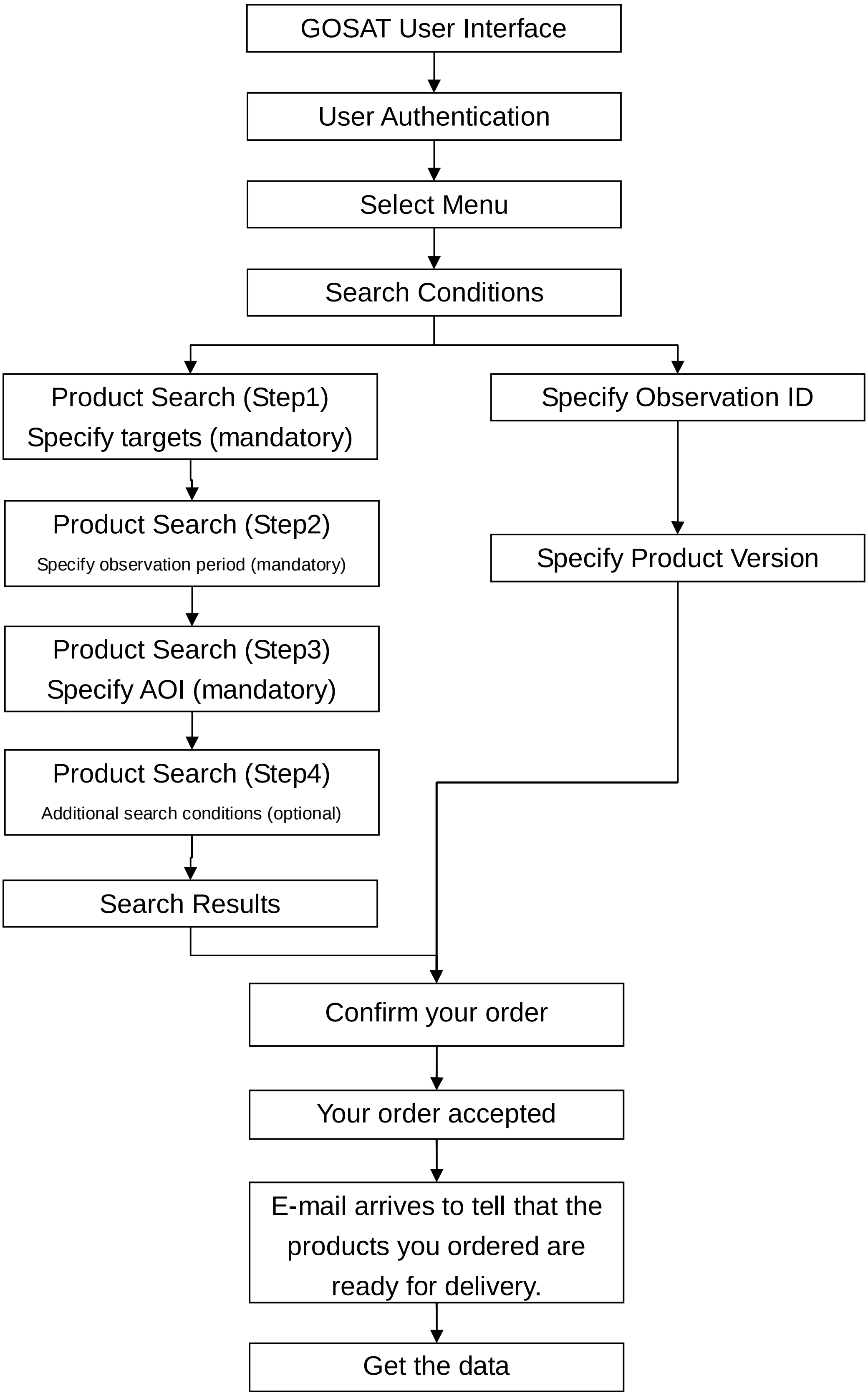


Fig. 7.3-5 Flow to show searching, ordering, and getting of GOSAT data products

For further information about searches and orders, please refer to the Instruction Manuals. You can get them by clicking "How to use this website" on the top page of GUIG. (see

Fig. 7.3-6)

Fig. 7.3-6 GUIG Instruction Manual traced from the top page

When the products you ordered are made ready, an E-mail as shown in Fig. 7.3-7 is automatically sent to you at the address you registered. Please log in to GUIG once again and download the generated products. (see Fig. 7.3-8)

ID: test@nies.go.jp
User Group: RA

Thank you for using the GOSAT data downloading service.
The data products you have ordered through
the GOSAT User Interface Gateway (GUIG)
[Order ID: 1004140002] are now downloadable
by following the procedures below.

Importantly, the uploaded data are available only for seven days.
As they will be removed from the site afterwards,
please download the products during the seven-day period.

Procedures:
1. Please log in to GUIG through the link below.
   https://data.gosat.nies.go.jp/gateway/gateway/MenuPage/open.do
2. You will be navigated to the "Ordered product list"
   by clicking "Product Download" on the Selection Menu page.
3. Then, select the data products you want to download from the list.

****

This e-mail was generated automatically, so please do not reply to this address.

****

Should you have any questions or require further assistance in using GUIG, please e-mail us at gosat-support@nies.go.jp. If you find this mail unknown, please kindly notify us.

GOSAT Support

Fig. 7.3-7 E-mail to inform the product generation completion

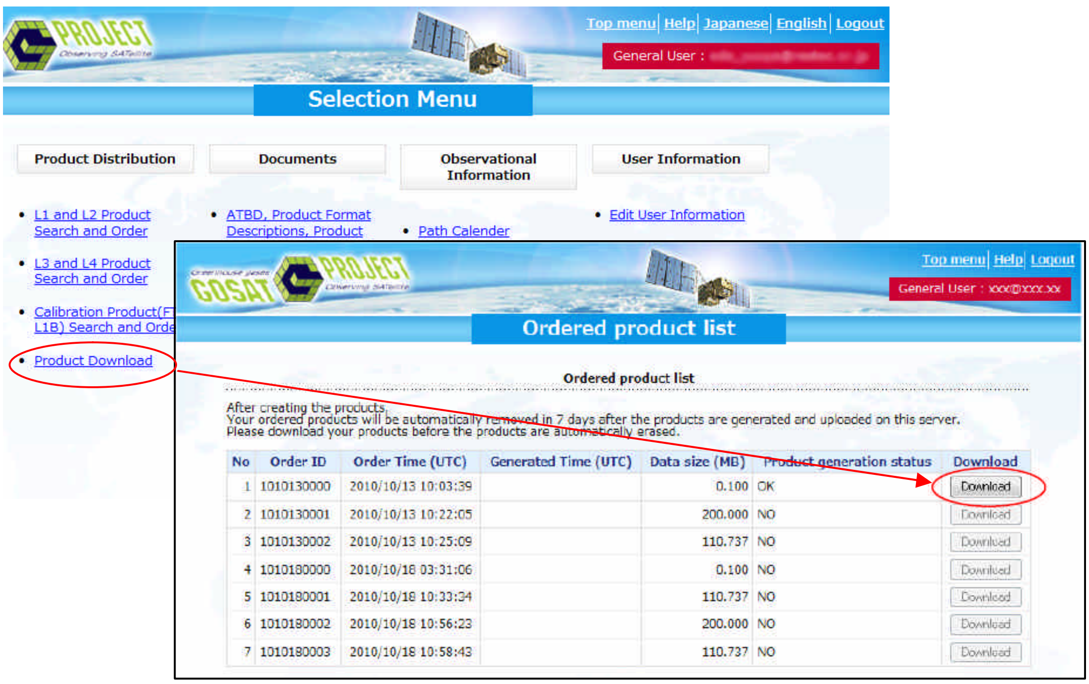


Fig. 7.3-8 How to get GOSAT data product

Regarding the image browser for the product you retrieved, click “Tools” on the top page of GUIG. (see
Fig. 7.3-9)

Fig. 7.3-9 Reference information on tools to display GOSAT data product

Chapter 8　Point of Contact

8.1　About This Handbook

Satellite Applications and Promotion Center,
Space Applications Mission Directorate, Japan Aerospace Exploration Agency
2-1-1, Sengen, Tsukuba-city, Ibaraki 305-8505 Japan
TEL: +81-29-868-4097, FAX: +81-29-868-5987
E-mail: GOSAT@jaxa.jp

8.2　About GOSAT Data

GOSAT Project Office, National Institute for Environmental Studies
16-2, Onogawa, Tsukuba-city, Ibaraki 305-8506 Japan

Acceptance time: 10:00-17:00 (JST), weekends and holidays excluded

- Whole (General content)

TEL: +81-29-850- 2035, E-mail: gosat-prj1@nies.go.jp

- RA relation

TEL: +81-29-850- 2035, E-mail: gosat-prj1@nies.go.jp

- About GOSAT product and service

TEL: +81-29-850- 2035, E-mail: gosat-support@nies.go.jp

Appendix 1 Acronyms

ADEOS	:	ADvanced Earth Observing Satellite
ADEOS-II	:	ADvanced Earth Observing Satellite -II
ALOS	:	Advanced Land Observing Satellite
AMSR-E	:	Advanced Microwave Scanning Radiometer-EOS
AO1	:	Alliance Organization 1
AO1*	:	Alliance Organization 1*
AO2	:	Alliance Organization 2
AOCS	:	Attitude & Orbit Control System
AOI	:	Area of Interest
APID	:	Application Processor ID
ASP	:	Analog Signal Processor
ASTER	:	Advanced Spaceborne Thermal Emission and Reflection radiometer
AT	:	Along Track
ATBD	:	Algorithm Theoretical Basis Documents
AVHRR	:	Advanced Very High Resolution Radiometer
CAM	:	CAMera
CCSDS	:	Consultative Committee for Space Data System
CI	:	Co Investigator
CT	:	Cross Track
DEM	:	Digital Elevation Model
DN	:	Digital Number
DT	:	Direct Transmission
ECMWF	:	European Centre for Medium-range Weather Forecasts
EIS	:	EORC Information System
EOC	:	Earth Observation Center
EPS	:	Electrical Power System
FFT	:	Fast Fourier Transform
GCP	:	Ground Control Point
GLI	:	GLobal Imager
GOSAT	:	Greenhouse gases Observing SATellite
GOSAT MMO	:	GOSAT Mission Management and Operation system
GPS	:	Global Positioning System

GU	:	General User
GPV	:	Grid Point Value
GUIG	:	GOSAT User Interface Gateway
HDF5	:	Hierarchical Data Format Version 5
HITRAN	:	HIgh resolution TRANsmission molecular absorption database
HK	:	House Keeping
IMC	:	Image Motion Compensation
InGaAs	:	Indium Gallium Arsenide
INT	:	INTegration hardware
JAXA	:	Japan Aerospace eXploration Agency
KSAT	:	Kongsberg Satellite Services
L	:	Level
LBLRTM	:	Line-By-Line Radiative Transfer Model
LLM	:	Light Load Mode
MAP	:	Maximum A Posteriori
MDHS	:	Mission Data Handling System
MDP	:	Mission Data Processor
MODIS	:	MODerate resolution Imaging Spectroradiometer
MOE	:	Ministry Of the Environment
MOS-1	:	Marine Observation Satellite-1
NASA	:	the National Aeronautics and Space Administration
NCSA	:	National Center for Supercomputing Application
NDSI	:	Normalized Difference Soil Index
NDVI	:	Normalized Difference Vegetation Index
NetCDF	:	Network Common Data Form
NIES	:	National Institute for Envionmental Studies
NIES GOSAT DHF	:	NIES GOSAT Data Handing Facility
NOAA	:	National Oceanic and Atmospheric Administration
OMI	:	Ozone Monitoring Instrument
PC-MCT	:	PhotoConductive -Mercury Cadmium Tellurium
PDL	:	PaDdLe
PFT		Pre-Flight Test
PI	:	Principal Investigator

PS	:	Project Staff
RA	:	Research Announcement, RA Investigator
RA*	:	RA* Investigator
RCS	:	Reaction Control Subsystem
SCIAMACHY	:	SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY
Si	:	Silicone
S-LLM	:	Super Light Load Mode
SMACS	:	Spacecraft MAnagement Control System
SNR	:	Signal to Noise Ratio
ST	:	Science Team member
ST*	:	Science Team member *
STR	:	STRucture
SvalSat	:	Svalbard Satellite station
SWIR	:	ShortWave InfraRed
TANSO	:	Thermal And Near infrared Sensor for carbon Observation
TANSO-CAI	:	TANSO-Cloud and Aerosol Imager
TANSO-FTS	:	TANSO-Fourier Transform Spectrometer
TCS	:	Thermal Control System
TEDA	:	Technical Data Acquisition Equipment
TIR	:	Thermal InfraRed
TKSC	:	TsuKuba Space Center
TT&C	:	Tracking Telemetry and Command
TTC-DH	:	Telemetry Tracking and Control subsystem-Data Handling
TTC-RF	:	Telemetry Tracking and Control subsystem-Radio Frequency
uFDS	:	unified Flight Dynamics System
USGS	:	United States Geological Survey
WDCGG	:	World Data Center for Greenhouse Gases
WMO	:	World Meteorological Organization
ZPD	:	Zero Path Difference

Appendix 2 Terminology

(1) Interferogram

A pattern of light intensity produced by a Fourier interferometer, which splits an incoming light beam into two paths and makes the two split beams meet again to interfere each other while the distance for one light beam to travel is gradually changed to make a difference from the distance for the other light beam.

(2) Sunglint

Sunglint generally means a specular reflection phenomenon seen on the surface of water reflecting the sunlight. A suglint point is in a plane defined by the three points, i.e. the sun, the sensor, and the sunglint point itself, at the location where incident angle and reflection angle have the same value. Sunglint observations by FTS are conducted including the neighborhood of the sunglint point wherefrom enough strength of reflected light comes in to the sensor.

(3) Sunglint region

Sunglint region is an area geographically defined on the earth's surface where sunglint is expected to occur; conventionally, ocean surface is specified as the region. The definition of such regions are given in the form shown below.

- As a polygon whose vertices are located on the surface of the earth, and their positions defined by the geographical latitude and longitude.
- Latitude and longitude are defined based on WGS84.
- Sides of the polygon is defined as a straight line connecting adjacent vertices on a Equidistant Cylindrical map.

(4) Sunglint operation span

A sunglint operation span is a stretch of the spacecraft trajectory wherefrom the sunglint operation is conducted.

Conventionally, nadir of the satellite is supposed to face the ocean when it is in the span. The definition of such spans are given in the form shown below.

- A pair of argument of latitudes is given to define the places to start and to stop the sunglint observation for each of the 44 passes of revolution. Further, different spans of observation can be assigned to different observation modes having different number of scanned points. For instance, five different pairs may be prepared for a path1 for each of the different modes of observation (i.e. 1, 3, 5, 7, and 9 point scans) to define an argument of latitude to start observation and an argument of latitude to stop observation. The values of argument of latitude here are the ones measured as true argument of latitude.

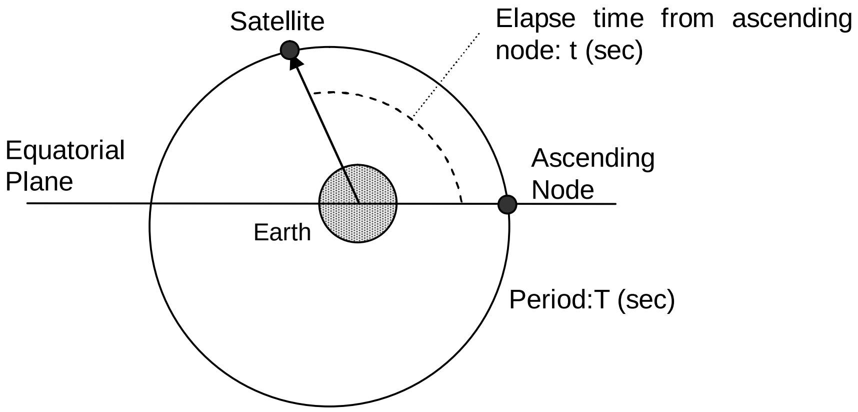
(5) Operation stages

Operation Stage		Description	Period
Launch Preparation Phase		Since the establishment of JAXA tracking and control team, until 4 hours after the launch.	
Launch Phase		Since 4 hours before the launch, until satellite separation from the vehicle.	
Initial Operation Phase	Critical operation period	The initial checkout operations are conducted.	for 3 months
	On-orbit checkout operation period		
Regular Operation Phase	Initial Validation and Calibration Operation Period	The initial validation and calibration are conducted.	for 3 months
	Regular Operation Period	Routine operations are conducted.	for 4.5 years
Post Operation Phase		Operations after regular operation phase.	Start at 5 years after the launch

(6) Mean argument of latitude

A mean argument of latitude (ϕ_m) is an angle measured from the ascending node and taken as a value proportional to the time elapsed since the passing of the node; described mathematically as follows.

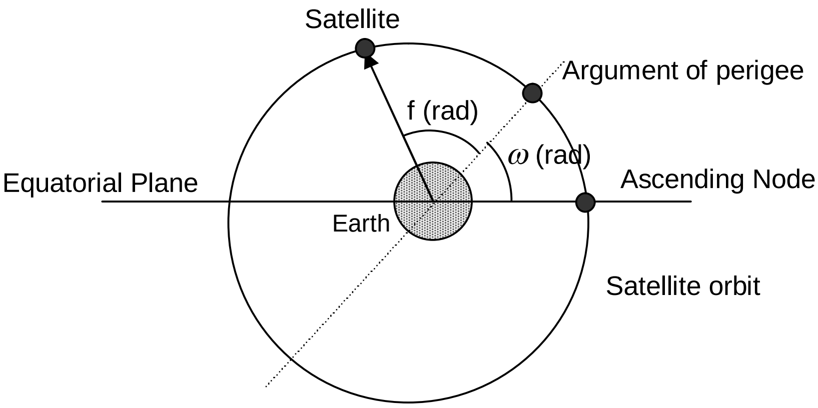
- $\phi_m = 2\pi \times t/T$ (rad)
  - ϕ_m : Mean argument of latitude (rad)
  - t : Elapse time from ascending node (sec)
  - T : Revolution period (sec)



(7) True argument of latitude

A true argument of latitude (ϕ_f) is an angle measured from the ascending node; described mathematically as follows.

- $\phi_f = \omega + f$
  - ϕ_f : True argument of latitude (rad)
  - ω : Argument of perigee (rad)
  - f : True anomaly (rad)



Appendix 3　Bibliography

- Bibliography concerning Specification of GOSAT Products
  - TANSO Level 1 Product Description Document (Document No.：MAS-1000067)
  - NIES GOSAT Product Format Descriptions
    (Document No.：NIES-GOSAT-PO-006)
  - Greenhouse gases Observing SATellite (GOSAT) Data Policy

- Bibliography concerning processing algorithm
  - ALGORITHM THEORETICAL BASIS DOCUMENT (ATBD) FOR CO_2 AND CH_4 COLUMUN AMOUNTS RETRIEVAL FROM GOSAT TANSO-FTS SWIR
    (Document No.：NIES-GOSAT-PO-014)
  - Algorithm Theoretical Basis Document for GOSAT TANSO-FTS L3
    (Document No.：NIES-GOSAT-PO-017)
  - Algorithm Theoretical Basis Document for GOSAT TANSO-CAI L2 cloud flag
    (Document No.：NIES-GOSAT-PO-016)
  - Research Announcement Appendix B　GOSAT/TANSO Calibration and Validation Plan and Overview of Processing Algorithms

- Bibliography concerning GOSAT data service
  - Instruction manual of the GOSAT User Interface Gateway (GUIG)