7th Edition (July 2016)

Global Greenhouse Gas Observation by Satellite

GOSAT Project

Greenhouse gases GOSAT PROJECT Observing SATellite

CGER

Greenhouse gases Observing SATellite

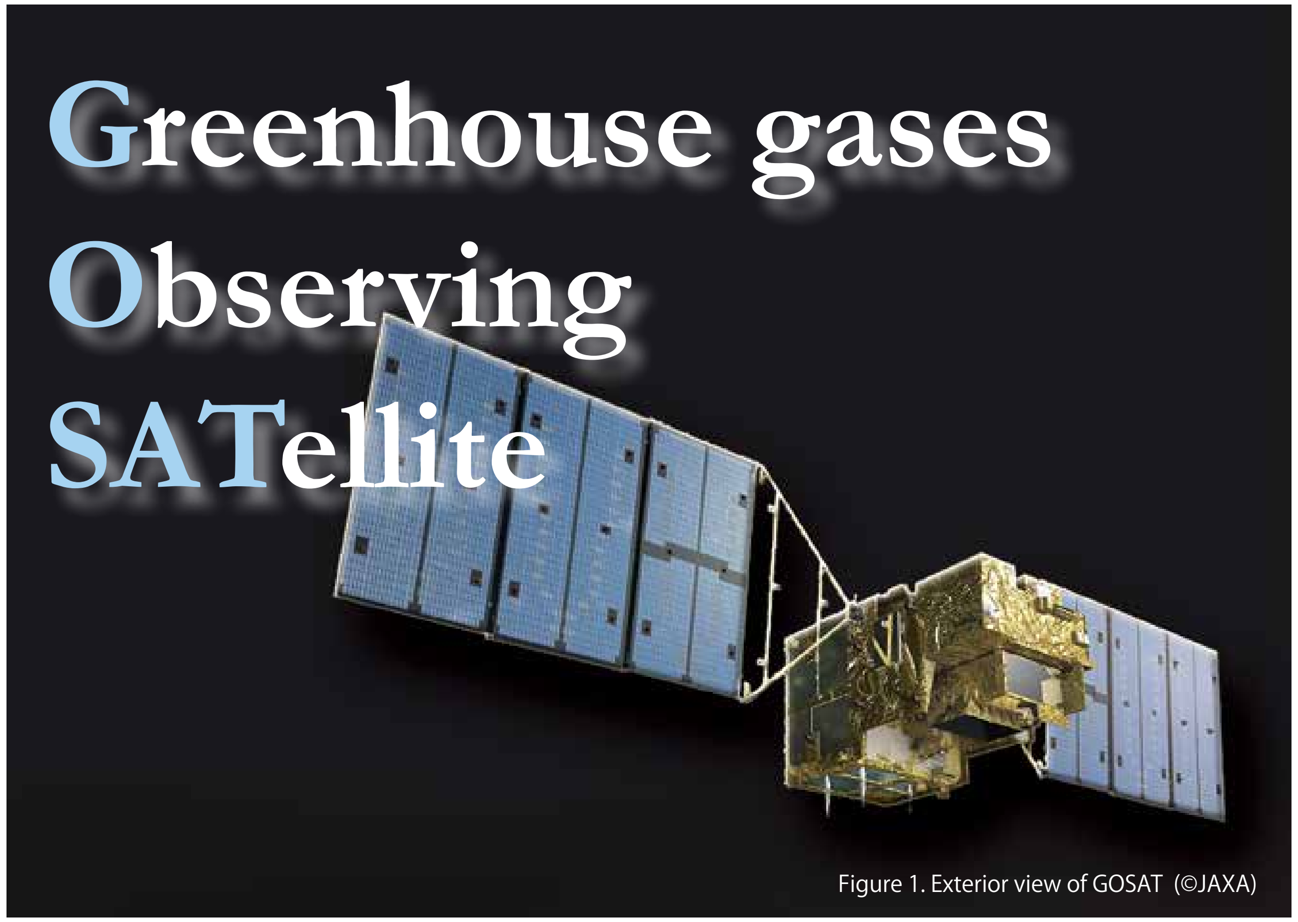

Figure 1. Exterior view of GOSAT (©JAXA)

The Greenhouse Gases Observing Satellite "IBUKI" (GOSAT) is the world's first spacecraft to measure the concentrations of carbon dioxide and methane, the two major greenhouse gases, from space (Figure 1). The spacecraft was launched successfully on January 23, 2009, and has now been continuing observation after completing its five years' nominal operation.

Through analyzing the GOSAT observational data, scientists will be able to ascertain the global distribution of carbon dioxide (CO_2) and methane (CH_4), and how the sources and sinks of these gases vary with seasons, years, and locations. These new findings will enhance scientific understanding on the causes of global warming. Also, they will serve as fundamental information for improving climate change prediction and establishing sound plans for mitigating global warming.

The GOSAT Project is a joint effort of the Ministry of the Environment (MOE), the National Institute for Environmental Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA) (Figure 2).

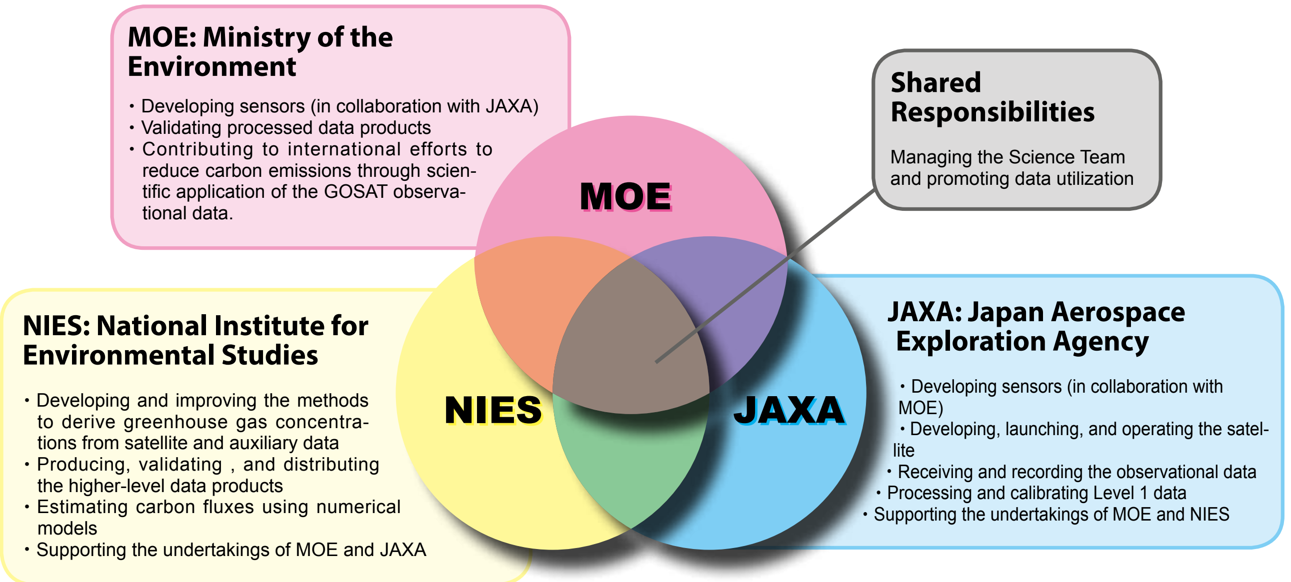

Figure 2. Role Sharing in the GOSAT Project.

1 Goals of the GOSAT Project

Due to mass consumption of fossil fuels in the expansion of industrial activities, worldwide emissions of CO_2 increased considerably during the past century. As shown in Figure 3, atmospheric CO_2 concentrations are rising very rapidly. CO_2 has a potential to warm the atmosphere and hence an increase in the concentrations leads to a rise in atmospheric temperatures. CO_2 and other chemical compounds, such as CH_4, nitrous oxide, and halocarbons, are designated as greenhouse gases that are subject to emission regulations under the Kyoto Protocol. CO_2 and CH_4 together account for near 90 percent of the total warming effect caused by these gases (Figure 4). The increased amount of greenhouse gases in the atmosphere is thought to cause not only rises in global average temperatures but also severe droughts and frequent floods. Such climatic changes may result in enormous damages.

For these reasons, the international community is moving toward reducing greenhouse gas emissions. In the Kyoto Protocol under the United Nations Framework Convention on Climate Change, emissions reduction targets for developed nations were agreed in 1997 and came into effect in February 2005. For promoting greenhouse gas reductions worldwide, it is essential to set rational reduction goals based on sure projections of climate change and its potential influences. At the same time, it is important to obtain accurate information on greenhouse gas emissions on national basis and evaluate their reduction measures based on that knowledge.

The primary purpose of the GOSAT Project is to estimate emissions and absorptions of the greenhouse gases on a subcontinental scale (several thousand kilometers square; see Figure 5) more accurately and to assist environmental administration in evaluating the carbon balance of the land ecosystem and making assessments of regional emissions and absorptions. Through analyzing the GOSAT data, scientists will accumulate new knowledge on the global distribution and temporal variation of the greenhouse gases, as well as the global carbon cycle and its influence on climate. These new findings will be utilized for predicting future climate change and assessing its impact. The Project also aims to expand existing earth observing satellite technologies, develop new methodologies for greenhouse gas measurement, and promote technological development necessary for future earth-observing satellites.

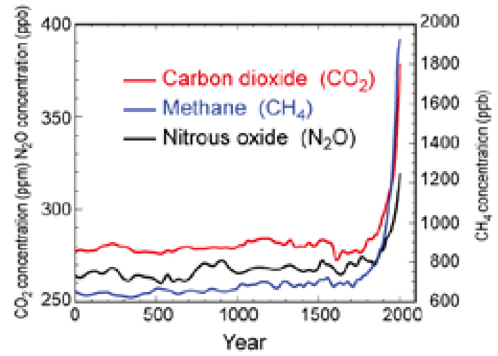

Figure 3. Changes in atmospheric concentrations of primary greenhouse gases. (Source: IPCC Fourth Assessment Report)

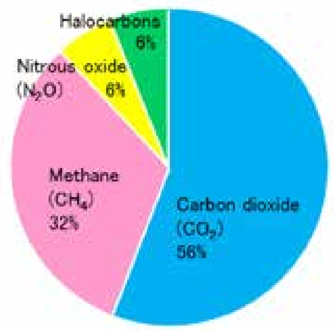

Figure 4. Contributions of primary greenhouse gases to the increase in atmospheric temperatures. The above figures are based on the best estimates of radiative forcing from 1750 to 2011. (Source: IPCC Fifth Assessment Report)

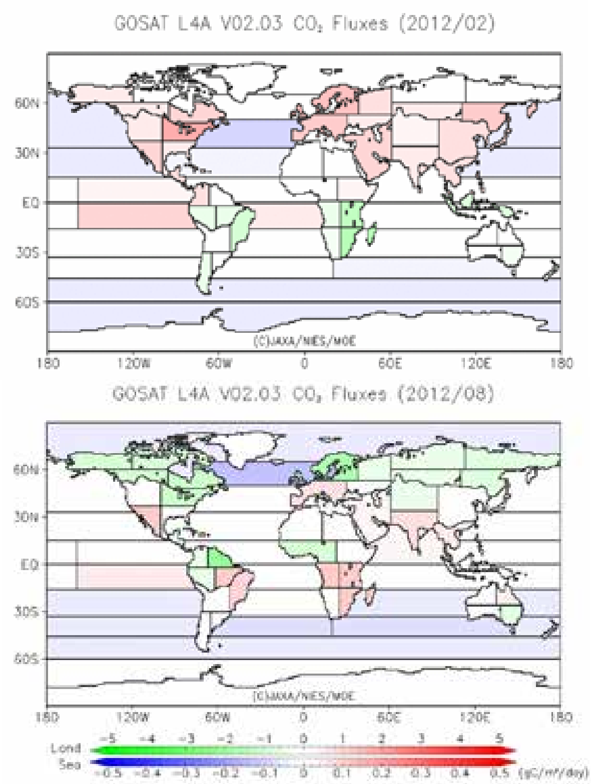

Figure 5. Sample estimates of global CO_2 sources and sinks ($gC/m^2/day$). February (upper), August (lower), 2012.

2 GOSAT Instruments and Observational Methods

GOSAT observes infrared light reflected and emitted from the earth's surface and the atmosphere. Column abundances of CO_2 and CH_4 are calculated from the observational data. The column abundance of a gas species is expressed as the number of the gas molecules in a column above a unit surface area.

GOSAT flies at an altitude of approximately 666 km and completes one revolution in about 100 minutes. The satellite returns to the same point in space in three days (Figure 6). The observation instrument onboard the satellite is called the Thermal And Near-infrared Sensor for carbon Observation (TANSO). TANSO is composed of two subunits: the Fourier Transform Spectrometer (FTS) and the Cloud and Aerosol Imager (CAI). Tables 1 and 2 summarize the target gas species, spectral coverage, and other specifications of these two instruments.

FTS is an instrument that utilizes optical interference. Within the instrument the incoming light is split into two beams which propagate in separate optical paths to create an optical path difference between the two. These beams are then recombined to cause interference. FTS measures the intensity of the interference by continuously changing the optical path length difference. A spectrum, which is distribution of light intensity over a span of wavelength, is obtained via performing mathematical operation called the Fourier transform on that measured data.

FTS observes sunlight reflected on the earth's surface and light emitted from the atmosphere and the surface. The former is observed in the spectral bands 1 through 3 of FTS in the daytime, and the latter is captured in band 4 during both the day and the night. Prior to reaching the detectors of the instrument, the light in the bands 1 through 3 (SWIR: Short-Wavelength InfraRed) is split into two orthogonally-polarized components (P and S components) and measured independently. The light in the band 4 (TIR: Thermal InfraRed), however, is not split. The instrument thereby observes the incoming light in seven different channels. The reflection character of sunlight over land and that of over water differ significantly. As seawater or lakes absorb the sunlight, FTS/SWIR is not suitable to observe these areas. Under a certain condition of FTS viewing direction and the position of the sun, FTS is able to catch the specular reflection of sunlight on water surface.

CAI visualizes the state of the atmosphere and the ground surface during the daytime. The image data from CAI are used to determine the cloud existence over an extended area that includes the FTS's field of view (FOV). When clouds and aerosols are detected in FOV, cloud characteristics and aerosol amounts are calculated. The information is used to correct the effects of the clouds and the aerosols on the spectra obtained with FTS.

During the three-day period, FTS takes fifty-six thousand measurements, covering the entire globe. Since the analysis is limited to areas under clear sky conditions, only two to five percent of the data collected are usable for calculating column abundances of CO_2 and CH_4. Nevertheless, the number of data points significantly surpasses the current number of ground monitoring stations, which is about 200. GOSAT serves to fill out the blanks in the ground observation network.

Table 1. Specifications of FTS

	Band 1	Band 2	Band 3	Band 4
Spectral coverage (μm)	0.758-0.775	1.56-1.72	1.92-2.08	5.56-14.3
Spectral resolution (cm^{-1})	0.2	0.2	0.2	0.2
Polarized light observation	Performed	Performed	Performed	Not Performed
Targeted gases	O_2	$CO_2 \cdot CH_4$	$CO_2 \cdot H_2O$	$CO_2 \cdot CH_4$
Angle of instantaneous field of view	15.8 mrad.(corresponds to 10.5 km when projected on the earth's surface)			
Time necessary for a single scanning (sec.)	4.0 , 2.0 , or 1.1 (depending on the scanning mode being used)			

* 1 μm = 1/1000 mm

Table 2. Specifications of CAI

	Band 1	Band 2	Band 3	Band 4
Spectral coverage (μm)	0.370-0.390 (0.380)	0.664-0.684 (0.674)	0.860-0.880 (0.870)	1.56-1.65 (1.60)
Targeted substances	Cloud and aerosol			
Swath (km)	1000	1000	1000	750
Spatial resolution at nadir (km)	0.5	0.5	0.5	1.5

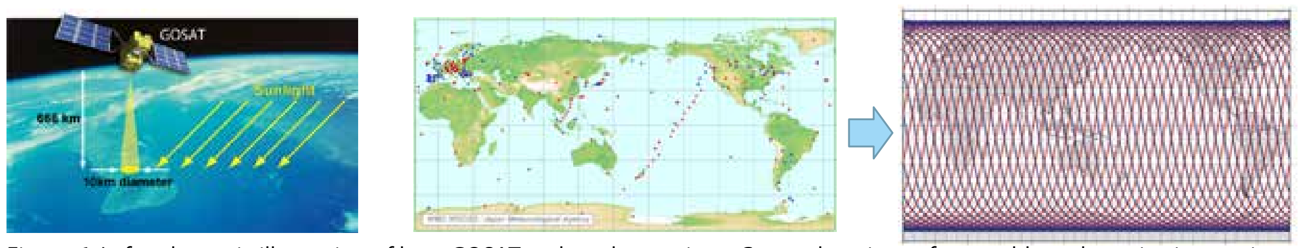

Figure 6. Left: schematic illustration of how GOSAT makes observations. Center: locations of ground-based monitoring stations (source: World Data Centre for Greenhouse Gases, as of October 2015). Right: Ground track of GOSAT for 3 days (44 revolutions).

3 Methods of Analyzing GOSAT Data

Data obtained with FTS and CAI are processed in the flow shown in Figure 7. Absorption spectra are obtained from the FTS observational data. The CAI data provide information on clouds and aerosols. These data are used together to calculate column abundances of CO_2 and CH_4 over observation points where interferences by clouds and aerosols are small. Sources and sinks as well as three-dimensional distributions of CO_2 and CH_4 concentrations are estimated using a global atmospheric transport model.

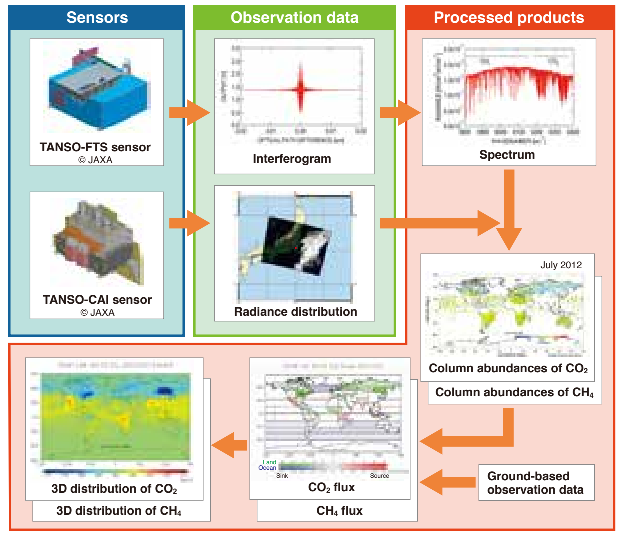

Figure 7. Outline of GOSAT data processing.

The molecules of CO_2 and CH_4 in the atmosphere absorb light of particular wavelengths. Hence, the amounts of CO_2 and CH_4 in an optical path can be calculated through measuring how much light is absorbed by these molecules. Figure 8 shows an example of absorption spectra that are obtained with FTS. The sawtoothed feature in the spectra indicates light absorption by gases such as CO_2 and CH_4, and the depression depth correlates with column abundances (see Note 3) of Table 3).

The spectral data are analyzed as follows. Among all spectra obtained with FTS, only those measured under no cloud interference within FOV are selected for further processing. This screening uses the images from CAI. Based on the absorption characteristics of the gases, the selected spectra are analyzed, using a numerical calculation scheme called the retrieval method, to calculate column abundances of CO_2 and CH_4. Changes in CO_2 concentration are most obvious near the surface of the earth. The CO_2 absorption bands near 1.6 μm and 2.0 μm are important since absorptions in these bands provide information on the near-surface concentrations. The absorption band around 14 μm is used for obtaining information mainly at altitudes above 2 km.

The column abundances of CO_2 and CH_4 are then averaged on a monthly or seasonal basis and processed into global distribution maps. The CO_2 and CH_4 global distribution data are used in the estimation of sources and sinks of CO_2 and CH_4 on a subcontinental scale (Figure 5). The sources and sinks are calculated by an inverse modeling using an atmospheric transport model.

The estimation of CO_2 and CH_4 sources and sinks once relied solely on ground-based observational data. Estimation errors were particularly large in Siberia, Asia, Africa, and South America where ground monitoring stations are located sparsely. GOSAT is capable of collecting observational data consistently over the clear-sky regions of the globe and hence is able to reduce errors in the estimates of their sources and sinks. Further, using these source and sink distribution data of CO_2 and CH_4 and the atmospheric transport model, the global distributions of CO_2 and CH_4 in three dimensions are simulated.

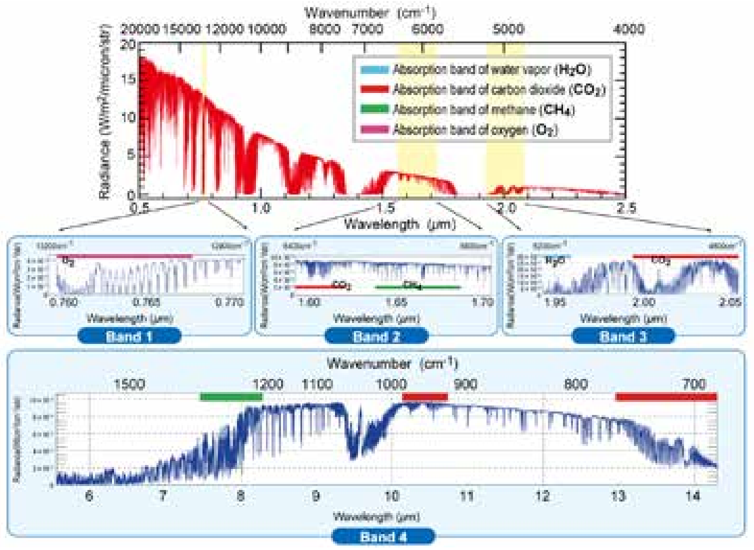

Figure 8.
Sample of FTS radiance spectra showing absorption bands of CO_2 and CH_4. Shown in the top panel is a model-simulated spectrum. Panels below present FTS Level 1B radiance spectra (explained in Chapter 5).

4 Data Processing and Data Product Distribution

The GOSAT observational data are routinely processed at the GOSAT Data Handling Facility (DHF), and the data products are distributed to general users through the GOSAT data product distribution website.

The development of the GOSAT DHF was completed in late 2008, and NIES has been maintaining it for the routine processing of the GOSAT data (Figure 9). GOSAT DHF collects the specific point observation requests from the qualified researchers (explained in Chapter 7). GOSAT DHF collates the observation requests of NIES and transfers them to JAXA. JAXA coordinates all observation requests to make the satellite operational plan and performs it as a routine task.

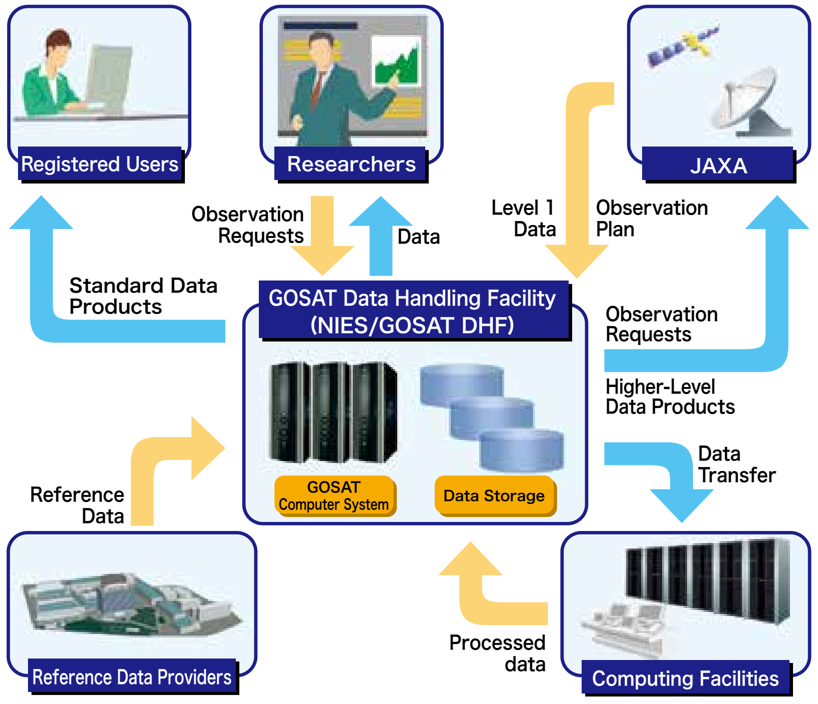

Figure 9. Workflow of GOSAT data processing.

The FTS and CAI data collected by the satellite are received and processed at JAXA Tsukuba Space Center. Then, these data are transferred to GOSAT DHF via a high-speed wide area network in Tsukuba. GOSAT DHF also collects some reference data, such as meteorological data necessary for the higher-level data processing, from the cooperating institutions. Using these reference data, the FTS observation data sent from JAXA are processed into column abundances, sources and sinks, and three-dimensional distributions of CO_2 and CH_4. Reference data used for validating the data products are also stored in this facility. All together, the amount of the data archived in seven years since 2009 will be around 900 terabytes.

Figure 10. GOSAT User Interface Gateway.
(http://data.gosat.nies.go.jp/)

The GOSAT data products are distributed through the GOSAT User Interface Gateway (GUIG), a website for GOSAT data distribution (Figure 10). Prior user registration is required for accessing the data products, and it can be done on the User Authentication page reached from the Login page of GUIG. Details on the data products are listed in Chapter 5.

5 GOSAT Data Products

Data products distributed from GOSAT DHF

Table 3 lists all types of the GOSAT data products provided for general users. The Level 1 data (FTS Level 1B, CAI Level 1B, and CAI Level 1B+ data) contain spectra and radiances acquired by the satellite. The higher level data products (FTS Level 2, CAI Level 2, FTS Level 3, CAI Level 3, Level 4A, and Level 4B data products) store retrieved physical quantities such as the atmospheric concentrations of CO_2 and CH_4. Data users can search and order these data products by accessing GUIG (Figure 10). Also there are some tools introduced on "Tools" of GUIG (http://data.gosat.nies.go.jp/) for users to read, check, and visualize the GOSAT data products.

Table 3. List of GOSAT data products distributed/to be distributed from GOSAT DHF to general users (as of March 2015).

Processing Level	Sensor/ Band	Product Name	Description	Unit	Format
L1B	FTS	FTS L1B data	Radiance spectral data obtained by performing Fourier transform on interferogram data	FTS scene	HDF5
	CAI	CAI L1B data	Radiance data (band-to-band and geometric corrections applied / data mapping not performed)	CAI frame	
L1B+	CAI	CAI L1B+ data	Radiance data (band-to-band and geometric corrections applied / data mapping performed)		
L2	FTS SWIR	L2 CO_2 column amount (SWIR)	CO_2 column abundance data retrieved from SWIR radiance spectral data	1 – multiple scans	HDF5
		L2 CH_4 column amount (SWIR)	CH_4 column abundance data retrieved from SWIR radiance spectral data		
		L2 H_2O column amount (SWIR) *1	H_2O column abundance data retrieved from SWIR radiance spectral data		
	FTS TIR	L2 CO_2 profile (TIR) *2	CO_2 vertical profile data retrieved from TIR radiance spectral data		
		L2 CH_4 profile (TIR) *2	CH_4 vertical profile data retrieved from TIR radiance spectral data		
	CAI	L2 cloud flag	Cloud coverage data	CAI frame	
L3	FTS SWIR	L3 global CO_2 distribution (SWIR)	CO_2 column-averaged mixing ratio data projected on a global map	Global (monthly average)	
		L3 global CH_4 distribution (SWIR)	CH_4 column-averaged mixing ratio data projected on a global map		
	CAI	L3 global radiance distribution	Global radiance distribution data (3 days' worth, including data for cloudy segments)	Global	
		L3 global reflectance distribution	Clear-sky radiance data (composed only of clear-sky segments from a month worth of data)		
		L3 NDVI	Vegetation index global distribution data (cloudy segments excluded)	Lat. 30° × Lon. 60°	
L4A	-	L4A global CO_2 flux	CO_2 flux per each of 64 global regions (monthly average)	64 regions across the globe, 1° mesh (annual)	Text / Net CDF
		L4A global CH_4 flux	CH_4 flux per each of 43 global regions (monthly average)	43 regions across the globe, 1° mesh (annual)	
L4B	-	L4B global CO_2 distribution	Three-dimentional global distribution of CO_2 concentration	Global 2.5° mesh (monthly)	Net CDF
		L4B global CH_4 distribution	Three-dimensional global distribution of CH_4 concentration		

*1 This product is newly defined as a standard product. (March, 2015)
*2 "FTS TIR L2 CO_2 profile" and "FTS TIR L2 CH_4 profile" newly include "FTS TIR L2 temperature profile" and "FTS TIR L2 H_2O profile" correspondingly.

Notes:
1) The details on the data processing flow are presented in Chapter 3.
2) SWIR and TIR stand for Short-Wavelength InfraRed and Thermal InfraRed, respectively. SWIR radiations are detected in the bands 1, 2, and 3 of FTS, and the band 4 captures TIR.
3) The column abundance of gas species is defined as the number of the gas molecules in a vertical unit column stretching from the ground surface to the top of the atmosphere.
4) An FTS scene and a CAI frame are equivalent to 1/60 of one orbital revolution.
5) HDF5 and netCDF are the types of the data file format used for distributing the data products. HDF5 : Hierarchical Data Format 5 ; netCDF: Network Common Data Form.
6) NDVI stands for Normalized Difference Vegetation Index.

Level 1B and 1B+ data

The FTS Level 1B data (Figure 8) are radiance spectra that are obtained by performing the Fourier transformation on the signals detected by FTS. The degrees to which the targeted gas species absorb the reflected and emitted light in each of the spectral bands can be seen on the data. A single data file of the FTS Level 1B data contains the radiance spectra obtained during 1/60 of an orbital revolution (defined as "one scene").

The CAI Level 1B data (Figure 11) are pixel-by-pixel radiances, which are converted from the digital counts of CAI by multiplying the given calibration factors.

The CAI Level 1B+ data (Figure 12) hold the same Level 1B radiance data, but the geographical locations of the image pixels are corrected for the skewness caused by the topographical roughness of the ground surface and are projected onto a map of the earth using interpolation. Each product file of the CAI Level 1B and Level 1B+ data contains the radiance data obtained during 1/60 of an orbital revolution (defined as "one frame").

Level 2 data products

The FTS SWIR Level 2 data products store the column abundances of CO_2 and CH_4 retrieved from the radiance spectra in the band 1 through 3 of FTS. The column abundance of a gas species is defined as the number of the gas molecule in a vertical unit column stretching from the ground surface to the top of the atmosphere. Figures 13 and 14 show the column-averaged mixing ratios of CO_2 and CH_4. The column-averaged mixing ratio of a gas species is given by dividing the column abundance of the gas by that of dry air. For improving the quality of the data products, the Level 2 data processing algorithm has continuously been updated. The validation of the Level 2 data products is also ongoing (explained in Chapter 6).

The FTS TIR Level 2 data products are vertical concentration profiles of CO_2 and CH_4 derived from the radiance spectra in the band 4 of FTS.

The CAI Level 2 cloud flag data product (Figure 15) stores the clear-sky confidence levels that are calculated from the CAI Level 1B data.

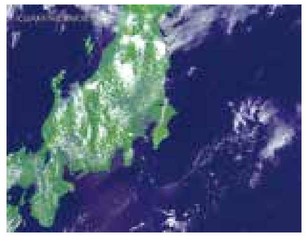

Figure 11.
CAI Level 1B data collected on July 17, 2010 over the vicinity of mainland Japan.

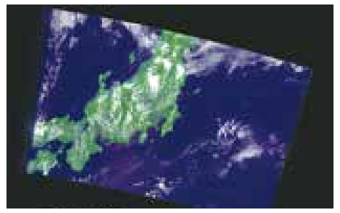

Figure 12.
CAI Level 1B+ data collected on July 17, 2010 over the vicinity of mainland Japan.

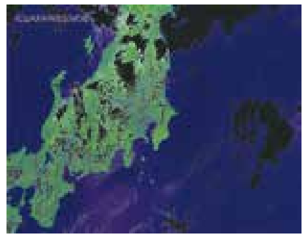

Figure 15.
CAI Level 2 cloud flag for July 17, 2010, overlaid with CAI Level 1B data (see Figure 11). Black indicates clouds.

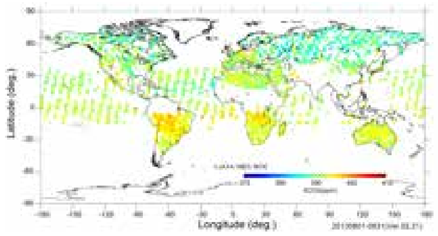

Figure 13.
FTS SWIR Level 2 CO_2 column abundance (2.5 deg mesh) for August 2013 derived for cloud-free regions. Blanks in white denote no available data.

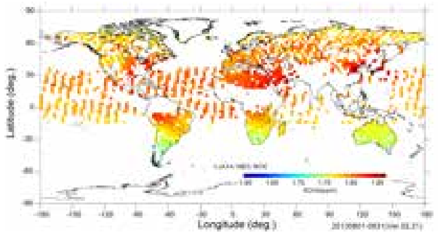

Figure 14.
FTS SWIR Level 2 CH_4 column abundance (2.5 deg mesh) for August 2013 derived for cloud-free regions. Blanks in white denote no available data.

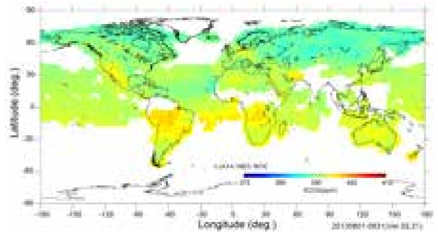

Figure 16.
FTS SWIR Level 3 global CO_2 distribution for August 2013 (in 2.5 deg mesh). Blanks in white denote data grids more than 500 km away from the nearest GOSAT scans.

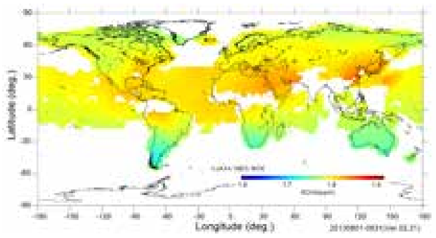

Figure 17.
FTS SWIR Level 3 global CH_4 distribution for August 2013 (in 2.5 deg mesh). Blanks in white denote data grids more than 500 km away from the nearest GOSAT scans.

Level 3 data products

The FTS SWIR Level 3 data products (Figures 16 and 17) store the monthly global distributions of CO_2 and CH_4 that are calculated from the FTS SWIR Level 2 column-averaged mixing ratios of CO_2 and CH_4. A geostatistical calculation technique called Kriging method is applied to estimate values for blank regions in the FTS SWIR Level 2 distributions. Values gridded into 2.5-degree cells are provided.

The CAI Level 3 global radiance distribution data product (Figure 18) is processed for every three consecutive days; the CAI radiance data collected during the days are assembled to give a global cloud distribution map.

The CAI Level 3 global reflectance distribution data product (Figure 19) shows the feature of the ground surface globally. These data are processed by selecting the least cloudy images from the CAI data collected in a month and consolidating them on a global map.

The Level 3 normalized difference vegetation index (NDVI) (Figure 20) data are generated by contrasting the CAI radiances in band 3, which are sensitive to ground surface vegetations, to those in band 2, which are less sensitive to the vegetations.

Level 4 data products

The Level 4A data products (Figure 21, 22 for CO_2) shows monthly averaged source/sink strengths (fluxes) of CO_2 and CH_4 in 64 and 43 regions respectively with their uncertainties that are inversely estimated from the FTS SWIR Level 2 column-averaged mixing ratios, ground-based observational data, and other meteorological data such as wind direction and velocity, using a global atmospheric transport model.

The Level 4B data products (Figure 23 for CO_2) presents global CO_2 and CH_4 concentrations in three dimensions calculated from the Level 4A data product using the atmospheric transport model. The data product has a horizontal resolution of 2.5°×2.5° and a time step of six hours.

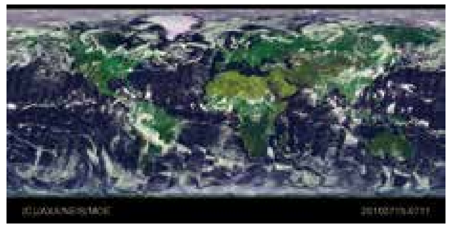

Figure 18.
CAI Level 3 global radiance distribution obtained between July 15 and 17, 2010.

Figure 19.
CAI Level 3 global reflectance distribution synthesized from cloud-free data obtained between July 1 and 31, 2010.

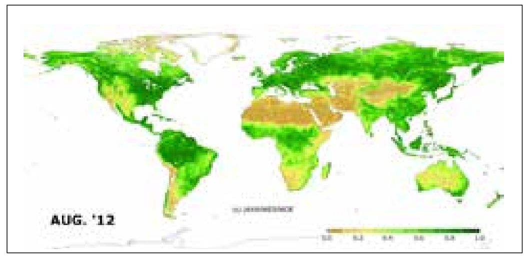

Figure 20.
CAI L3 NDVI Product. Global map of normalized difference vegetation index (NDVI) for August 2013.

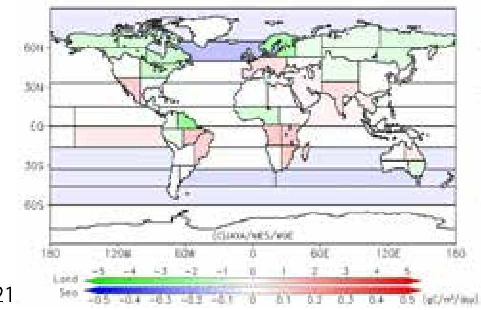

Figure 21.
L4A global CO_2 flux. A sample map of regional CO_2 flux estimates, August 2012.

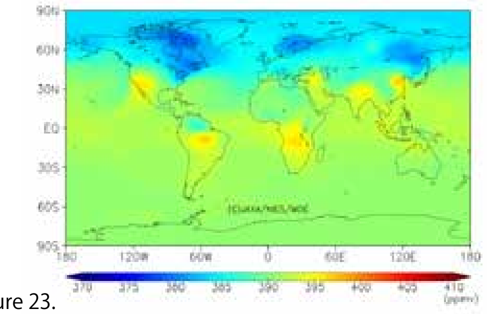

Figure 23.
L4B global CO_2 distribution. A sample map extracted from global three-dimensional CO_2 distribution, at an altitude of approx. 800 m (0.925 level on a hybrid sigma-pressure coordinate), August 2012.

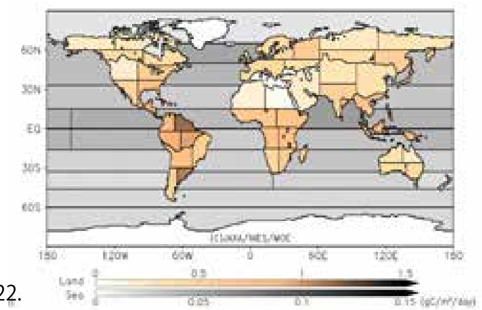

Figure 22.
L4A global CO_2 flux. A sample map of regional CO_2 flux uncertainties, August 2012.

6 Validation of GOSAT Data Products

In order for the GOSAT data products to be utilized meaningfully in the science community, uncertainties associated with the data products need to be clarified through validation. High-precision data obtained independently by ground-based instruments and aircrafts are used to validate the data products. Improvements in the data processing algorithms are made based on the validation results.

Validation of the GOSAT data products acquired through the routine processing of the GOSAT observational data (Figure 7) is necessary in order for the data products to be used meaningfully in the science community. The precision and bias of the data products must be clarified. To this end, the GOSAT data validation team has been utilizing high-precision reference data obtained through ground-based and airborne measurements (Figure 24). For validating the Level 2 column abundances of CO_2 and CH_4, the team uses data from ground-based high-resolution Fourier transform spectrometers and in-situ observation instruments installed on aircrafts. Properties of clouds and aerosols calculated in the routine data processing are checked against the data obtained with remote sensing instruments such as ground-based sky radiometers and lidars. The estimated source/sink strengths and three-dimensional distributions of CO_2 and CH_4 are compared with other model outputs.

The data validation team has carried out a series of data validation activities and compared the Level 2 data products to the ground-based and airborne reference data. Figure 25 shows the sounding locations of the ground-based high-resolution Fourier transform spectrometers in the Total Carbon Column Observing Network and other independent sites (http://tccon.ornl.gov/). Data obtained in Japan, Europe, Oceania, and North America have been used in these validation activities. Also, those data have been employed which are collected in Japan Airlines' CONTRAIL (Comprehensive Observation Network for Trace gases by Airliner) project and the US National Oceanic and Atmospheric Administration's airborne measurement program. The results of the comparison (as of May 2014) indicated that the retrieved Level 2 CO_2 and CH_4 column abundances were slightly lower than the reference values, and the latitudinal distribution pattern (i.e., zonal mean) of the Level 2 data were broadly consistent with those of the reference values. The data product validation activities are continued, and the results acquired are used for reference in the further continued improvement of the data processing algorithms.

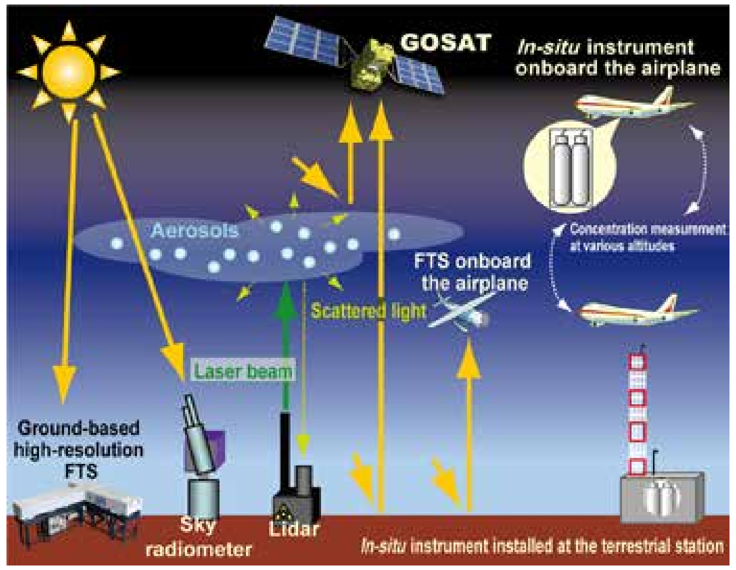

Figure 24.
Schematic illustration of the data product validation experiment

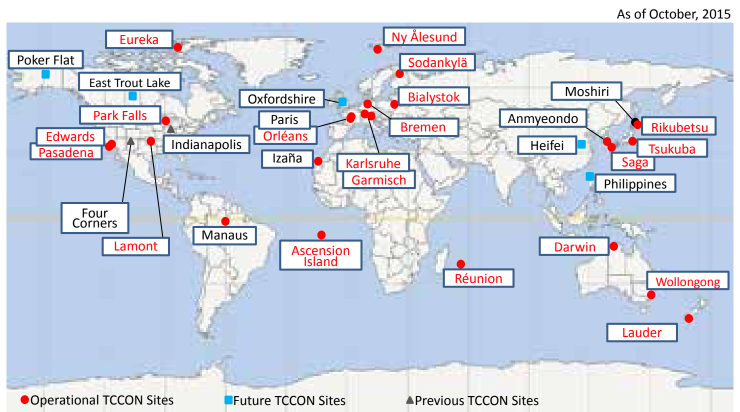

Figure 25.
Sounding locations of the ground-based high-resolution Fourier transform spectrometers in the Total Carbon Column Observing Network. Sites shown in **red** have been used for the data validation.

7 Project Information and Research Announcements

The latest information is posted on the GOSAT Project website and in the Project's newsletter. Back issues of the newsletter are available on the website. The GOSAT Project has solicited research proposals from scientists around the world to encourage further use of the GOSAT data.

The website of GOSAT Project (Figure 26) posts the latest news of the project as well as other information such as technical details, project results, GOSAT research announcements, and back issues of GOSAT PROJECT NEWSLETTER.

Data users can search and order GOSAT data products at GUIG, the GOSAT data product distribution site (Figure 10). There, the users can also view selected data products plotted on global maps.

Figure 27 shows the project website of the upcoming successor GOSAT-2, where the latest information is provided such as requirements for the spacecraft and instruments.

Figure 26. Top page of GOSAT Project Website (http://www.gosat.nies.go.jp/)

Figure 27. Top page of GOSAT-2 Project Website (http://www.gosat-2.nies.go.jp/)

Through research announcements for ten times from 2008 to 2016, the GOSAT Project solicited research proposals from scientists worldwide in the following five research areas: instrument calibration, data processing algorithm development, carbon balance estimation and atmospheric transport modeling, data validation, and data application. A total of 126 proposals has been selected (Table 4). The lists of selected proposals are posted on the Project website (http://www.gosat.nies.go.jp/eng/proposal/proposal.htm). Scientists not only in Japan but also around the world responded to the research announcements, showing active interests in the Project. Table 5 shows the number of the selected research proposals per nation. The meetings of principal investigators were held at Tokyo, Japan in 2008, Kyoto, Japan in 2010, Edinburgh, UK in 2011, Pasadena, USA in 2012, Yokohama, Japan in 2013, Tsukuba, Japan in 2014,Pasadena, USA in 2015, and Kyoto, Japan in 2016. Attended scientists shared the latest information on their researches and discussed their progresses.

Table 4. Number of selected research proposals per research area.

	2008	2009	2010	2011-16	Total
Calibration	4				4
Data Processing Algorithm	11	7	2	2	22
Data Validation	15	7	1	7	30
Source-Sink Estimation	6	8	3	0	17
Data Application	16	14	9	11	50
Data Application / Validation			2		2
Source-Sink Estimation / Data Application			1		1
Total	52	36	18	20	126

Table 5. Number of selected research proposals per nation.

Country	2008	2009	2010	2011-16	Total
Japan	23	8	1	4	36
USA	7	8	3	4	22
Germany	6	2		2	10
China	1		2	3	6
Canada	3		2		5
France	2	2	1		5
Netherlands	3	1	1		5
UK	2	3			5
Russia	4				4
Finland		2	1	1	4
Australia			2	1	3
India		1	1		2
Italy		2			2
Korea		1	1		2
Spain		1	1		2
Indonesia			1	1	2
Belgium		1			1
Brazil		1			1
Czech		1			1
New Zealand	1				1
Norway		1		1	2
Singapore		1			1
Malaysia				1	1
Taiwan, ROC			1		1
Belarus				1	1
Total	52	36	18	20	126

8 Organization and Plans

GOSAT has been operating properly since the spacecraft was placed in orbit on January 23, 2009. The initial calibration and validation of the instruments on-board started three months later, and the routine observation has been continued since July 28. The distribution of the Level 1 data to the general public was initiated on October 29 of the same year. This was followed by the release of the Level 2 and Level 3 data products in 2010, and Level 4 products in 2012.

A project unit in NIES carries out the GOSAT Project. This unit implements the primary tasks of the GOSAT Project, which include developing algorithms for calculating column abundances of CO_2 and CH_4 from the GOSAT observational data, validating and evaluating the results, and developing and improving numerical models for estimating the sources and sinks of CO_2 and CH_4. The unit also operates GOSAT DHF and provides information to data users (Chapter 4). In FY2016, Satellite Observation Center was newly established to strengthen the administrative and operational structure for GOSAT and GOSAT-2 (Figure 28).

The CO_2 and CH_4 Level 4 data products have been released since December 2012 and July 2014, respectively. For updating the released data products, the Project will continue the tasks of renewing the data processing algorithm, processing and re-processing the observational data with the improved algorithms, and validating the acquired data products.

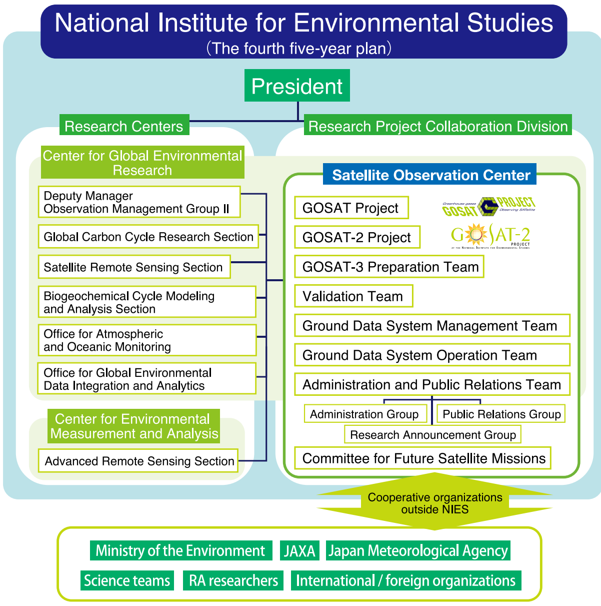

Figure 28. Satellite Observation Center organization (as of July. 2016).

Greenhouse gases Observing SATellite

GOSAT Project

Ministry of the Environment
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- *For inquiries on the distribution of the GOSAT data products, please visit our website at*...http://data.gosat.nies.go.jp/
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