# Greenhouse gases Observing SATellite (GOSAT) Ground Systems

● Masato Yokomizo

*(Manuscript received December 12, 2008)*

**The Japan Aerospace Exploration Agency (JAXA) is an independent administrative agency responsible for the development and utilization of space and R&D in the aviation field. The mission of JAXA's Greenhouse gases Observing SATellite (GOSAT) is to obtain basic data on global warming by monitoring greenhouse gases, and its launching is scheduled during fiscal 2008. Fujitsu's operational know-how accumulated over many years of building onboard satellite systems and satellite ground systems, and its software development technologies and computer hardware have been applied in GOSAT ground systems. This paper examines general satellite ground systems, the ground systems for GOSAT, as well as the systems, computers and middleware for which Fujitsu is responsible. The paper also describes the ground systems for determining orbits and planning observation in particular detail, given Fujitsu's major contribution to such systems.**

## 1. Introduction

The Japan Aerospace Exploration Agency (JAXA) is an independent administrative agency responsible for the development and utilization of space and R&D in aviation. JAXA engages in projects to develop global environmental monitoring systems for contributing to a safer and more comfortable world in which to live, as part of its long-term vision. Concerns over global warming have been growing since the latter half of the 1990s, and the adoption of the Kyoto Protocol in 1997 obliged advanced nations to reduce greenhouse gas emissions, along with stronger demands for these nations to monitor terrestrial, marine and space environments. As part of Japan's contribution to this international commitment, JAXA will launch the Greenhouse gases Observing SATellite (GOSAT) during fiscal 2008. GOSAT is a joint development project involving JAXA, the Ministry of the Environment, and the National Institute of Environmental Studies (NIES), under which JAXA is charged with developing the satellite and monitoring sensors and the Ministry and NIES are primarily responsible for utilizing the data obtained.[1] In the project, sensors mounted on GOSAT will monitor and analyze infrared radiation emitted by the earth into space in order to compute concentrations of greenhouse gases in the atmosphere. Launching GOSAT into orbit will make it possible to measure the distribution of greenhouse gas concentrations for virtually all parts of the earth's surface at intervals of once every three days, help us better understand the discharge and absorption of greenhouse gases, and contribute to international efforts to prevent global warming.

This paper gives an overview of JAXA's GOSAT ground systems and describes the subsystems for which Fujitsu and Fujitsu Advanced Solutions (FASOL) are responsible.

# 2. Overview of ground systems for earth observing satellites

Earth observation satellites (hereafter called "satellite") generally consist of mission equipment with which to accomplish intended objectives and bus systems that provide services necessary to operate the mission equipment. Bus systems are a core component of satellites and mainly comprise communication subsystems for communicating with the ground, electrical power subsystems for supplying power generated by solar arrays to each type of equipment, and systems for processing and recording data from the various units of equipment. The sensors are the mission equipment of GOSAT, since its objective is to measure greenhouse gas emissions.

Satellite operation is divided into an initial critical operation phase where the satellite is launched by rocket and set into the prescheduled orbit for carrying out its mission, and with the operation of all equipment being checked, and a nominal operation phase during which it carries out its mission. This paper primarily focuses on the nominal operation phase. **Figure 1** outlines the nominal operation phase and the following describes its stages and the procedures in detail.

## 2.1 Planning [Figure 1 1)]

In this stage, plans are made for satellite operation (bus systems, mission equipment).

In operation plans, ambiguous user requests are converted into commands that will operate devices installed onboard the satellite at the specified times.

1) Mission observation requests [Figure 1 1)]

The users of mission data issue observation requests.

2) Observation planning [Figure 1 1) ②]

Multiple requests for mission devices are subject to prioritizing, resulting in a plan being

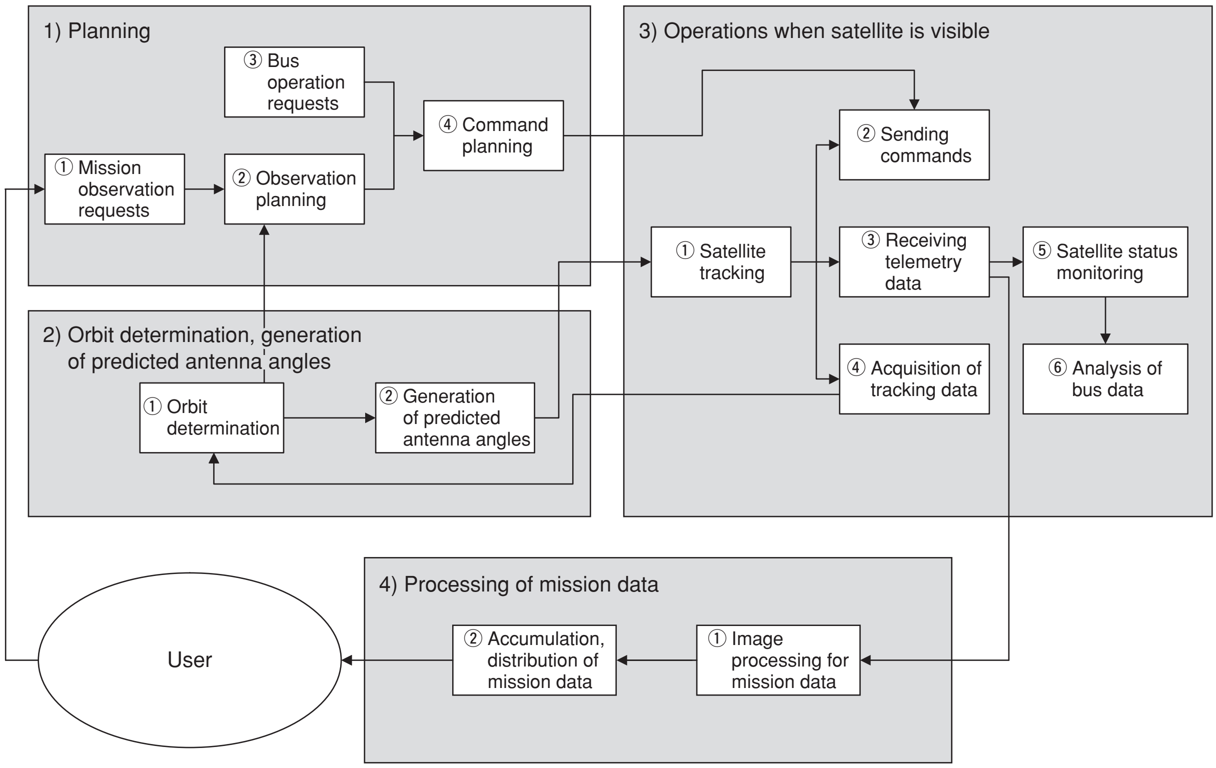


Figure 1
Satellite operation.

created for commands that operate the mission devices at the specified times.

3) Bus operation requests [Figure 1 1) ③]

Based on these requests, an operation plan (also called a satellite operation plan) is created for operating the bus devices.

4) Command planning [Figure 1 1) ④]

In command planning, a plan is made for commands sent to the satellite during a time when the satellite is "visible" to a tracking station (where it can be tracked by an antenna) based on the results of 2) and 3) above.

## 2.2 Orbit determination, generation of predicted antenna angles [Figure 1 2)]

1) Orbit determination [Figure 1 2) ①]

If the precise position of the satellite were unknown, we could not receive data from the satellite or send control commands to it. Newton's equations of motion are used to express satellite orbits, and satellite position and speed can be obtained through numerical integration by using these equations. However, real satellites are subject to gravity, small amounts of air resistance, and other influences that create accumulative discrepancies in the results determined by the equations of motion.[2)]

Therefore, when the tracking station's antenna can track the satellite, the range data (time for a round-trip of radio waves) and Doppler data (magnitude of frequency changes) obtained by the tracking station in transmitting radio waves to the satellite are used to periodically calculate altitude and speed components in order to determine orbit.[3)]

2) Generation of predicted antenna angles [Figure 1 2) ②]

The Flight Dynamics System of a tracking station controlling the satellite generates antenna angle predictions based on the orbit determination value. The Flight Dynamics System uses such orbit determination values to predict antenna angles several days ahead and distributes the data to other tracking stations.

## 2.3 Operations when satellite is visible [Figure 1 3)]

Since a satellite orbiting at an altitude of about 600 km takes around 90 minutes to complete one orbit of the earth, a single tracking station can track it for about 10 minutes. During operations when the satellite is visible to the tracking station, it sends commands to and receives data from the satellite, and thus acquires tracking data from the satellite.

1) Satellite tracking [Figure 1 3) ①]

A tracking station locks on to the satellite using antenna angle predictions and receives radio waves from the satellite while tracking it, and also transmits commands to it.

2) Sending commands [Figure 1 3) ②]

Based on the command plan, the Satellite Tracking and Control System sends commands to the satellite tracking station for transmission to the satellite as radio waves via the tracking station's antenna.

3) Receiving telemetry data [Figure 1 3) ③]

Telemetry data indicates the status of satellite bus and mission devices, and includes the observation data from mission devices. The Satellite Tracking and Control System and Satellite Data Processing convert telemetry data into meaningful physical quantities and status data.

4) Acquisition of tracking data [Figure 1 3) ④]

The tracking station acquires the range data and Doppler data needed for orbit determination.

5) Satellite status monitoring [Figure 1 3) ⑤]

While the satellite is visible, the telemetry data received by the Satellite Control System is used to monitor satellite status.

6) Analysis of bus data [Figure1 3) ⑥]

During the period when the satellite is not visible, bus status is analyzed from data received by Satellite Data Processing.

## 2.4 Processing of mission data [Figure 1 4)]

1) Image processing for mission data

[Figure 1 4) ①]

Image processing is performed on telemetry data from mission devices for conversion into graphics, graphs, and other forms that are easier to comprehend. Corrective processing is also conducted to raise the level of data accuracy.

2) Accumulation, distribution of mission data [Figure 1 4) ②]

Processed mission data is accumulated and saved on disk, and then distributed to users.

## 3. Overview of GOSAT ground systems

The previous section gave general descriptions of satellite operation. This section describes the ground systems used in GOSAT operation. **Figure 2** shows the composition of GOSAT ground systems. The following describes the individual units of equipment and systems.

1) Station equipment (JAXA tracking stations, JAXA Earth Observation Center, Svalbard Station)

JAXA tracking stations, JAXA's Earth Observation Center (EOC) in Hatoyama Town, Saitama Prefecture, and the Svalbard Station in Norway are used for GOSAT. The JAXA tracking stations receive telemetry data other than that from mission devices (hereafter called "sensor"), send commands, and acquire tracking data. The EOC and Svalbard Station mainly receive telemetry data from sensors. The EOC is equipped with antenna equipment, earth observation

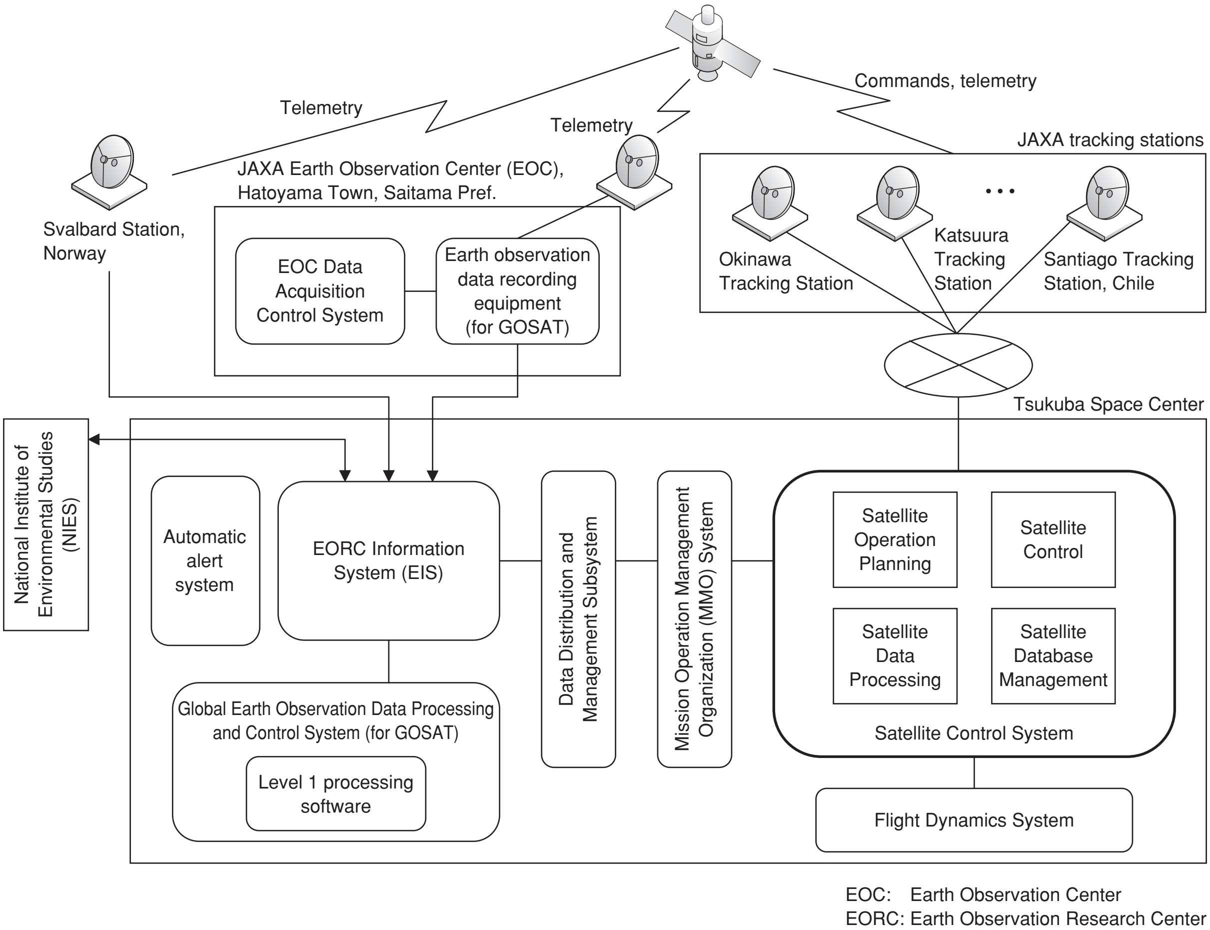


Figure 2
GOSAT ground systems.

data recording equipment for GOSAT (hereafter called “recording equipment”), and the EOC Data Acquisition Control System. The recording equipment accumulates the telemetry data received and then transmits it to the Tsukuba Space Center. The EOC Data Acquisition Control System creates antenna utilization plans for efficient use of the EOC’s multiple antennas in response to antenna utilization requests from GOSAT and several other satellites, and in accordance with a predetermined order of precedence.

2) Satellite Control System

The Satellite Control System consists of four subsystems: Satellite Operation Planning, Satellite Control, Satellite Data Processing, and Satellite Database Management.

- Satellite Operation Planning creates command plans based on bus operation plans and observation plans received from the Mission Operation Management Organization (MMO) System.
- Satellite Control sends commands to GOSAT in accordance with the command plan and receives telemetry data in order to monitor satellite status in real time.
- Satellite Data Processing analyses satellite status from telemetry data as well as data available when the satellite is not visible.
- Satellite Database Management manages data for converting telemetry data into engineering values, command code conversion data, and other satellite-related data as a database.

3) Flight Dynamics System

The Flight Dynamics System determines the orbit based on tracking data acquired by station equipment. By using the results of orbit determination, it forecasts future satellite positions and speeds and predicts antenna angles.

4) MMO System

This system receives observation requests from observation data users, makes priority adjustments, draws up commands and execution time plans to operate sensors, and then sends the resulting commands and schedules to the Satellite Control System (Satellite Operation Planning).

5) Data Distribution and Management Subsystem

This common fundamental subsystem transmits data required for operations among the Satellite Control System, MMO System, and Flight Dynamics System.

6) Global Earth data Processing and Control System for GOSAT (hereafter called “Processing and Control System”)

The Processing and Control System converts observation data into meaningful physical quantities and waits until various items of data become available before starting the GOSAT-specific processing unit (hereafter called “Level 1 processing software”). The Level 1 processing software converts data into physical quantities and image data in accordance with sensor algorithm specifications. The Processing and Control System manages the processing status of the Level 1 processing software and sends the processing results to the EORC Information System.

7) EORC Information System (EIS)

EIS performs the data management required for mission operation. More specifically, it stores various items of data required for mission operation, is responsible for data transmission (sending and receiving) among recording and other units of GOSAT ground system equipment, as well as with such external organizations as NIES and the Svalbard Station, and stores the source data.

8) Automatic Alert System

This system monitors the essential equipment in GOSAT ground systems, alerts operators to equipment malfunctions by means of alarms or E-mail notices, and displays the status of equipment.

**Table 1** lists the system functions and major computer hardware/middleware components of GOSAT ground systems for which Fujitsu is responsible.

## 4. Contribution of Fujitsu technologies

This section examines the GOSAT ground systems to which Fujitsu has contributed through its operational know-how and technologies. Fujitsu has made a particularly noteworthy contribution to the development and operation of ground systems by applying its operational know-how accumulated through the development and provision of similar systems and development technologies over the years in the Flight Dynamics System, Mission Operation and Control System, and EIS.

1) Orbit determining technology: Flight Dynamics System

Unlike conventional satellites, GOSAT is equipped with a GPS receiver, making it capable of autonomous navigation in nominal operation. The orbits of conventional satellites are determined by using range data and Doppler data acquired by tracking stations, but GOSAT uses onboard GPS data for orbit determination. GOSAT is JAXA's first satellite to do this in nominal satellite operation. The orbit determining technology developed by Fujitsu is based on know-how and experience accumulated since the beginning of JAXA's satellite operations, and can sustain 10 years of operations.

2) Sensor operation planning technologies: MMO System

GOSAT is operated based on requests from observation data users. Many requests are vague

Table 1
Functions under Fujitsu's responsibility.

| System | Functions under Fujitsu's responsibly | Main computer hardware | Main middleware |
|---|---|---|---|
| EOC Data Acquisition Control System | Satellite antenna utilization planning | PRIMERGY RX300<br>ETERNUS4000 | Interstage<br>PRIMECLUSTER<br>Symfoware |
| Satellite control system (Satellite Data Processing) | Accumulation, evaluation, and provision of bus telemetry data | PRIMEPOWER250 | — |
| Flight Dynamics System | Satellite orbit determination and antenna angle prediction | PRIMEPOWER450<br>PRIMEPOWER250<br>ETERNUS3000 | Interstage<br>ORACLE<br>CyberGRIP<br>CentricMGR |
| Data Distribution and Management Subsystem | Sending/receiving data needed for operation | PRIMEPOWER250<br>ETERNUS4000 | PRIMECLUSTER |
| MMO System | Observation planning | PRIMERGY RX300<br>ETERNUS SX300 | Interstage<br>PRIMECLUSTER<br>Symfoware<br>Systemwalker |
| EORC Information System | Accumulation, distribution of observation and other data | | |
| Global Earth Observation Data Processing and Control System | Management of observation data production | PRIMEPOWER450<br>ETERNUS4000<br>PRIMERGY RX200<br>PRIMERGY TX150<br>NR1000F350 | Interstage<br>PRIMECLUSTER<br>Symfoware<br>Systemwalker<br>Platform LSF |
| Level 1 processing software | — | PRIMERGY RX200 | Platform LSF<br>Systemwalker |
| Automatic Alert System | Notification of alerts for individual ground systems and display of system status | PRIMERGY TX200<br>ETERNUS SX300 | PowerGress<br>PRIMECLUSTER |

and lack a unique interpretation. For example, a request may call for observing a certain point on the earth's surface within a certain period when observation is possible at any time or as long as possible beyond a specified period. Such vague requests eventually require that execution times be determined for commands that operate the sensors mounted on GOSAT. A major role of the MMO system is to convert the details of these vague requests into operation plans (commands and execution times).

The major technologies needed by the MMO system to convert requests into operation plans are Operation Time Optimization, Sensor Parameter Calculation, and Data Capacity Management.

- Operation Time Optimization calculates the time when an observation request can be carried out based on its details, and optimizes the arrangement of requests so that as many requests as possible may be carried out.
- Sensor Parameter Calculation calculates the sensor angles of view and other sensor parameters, and generates sensor control commands. In response to a request made to observe Tsukuba in Japan, for instance, when the satellite will pass over Japan is first determined from its orbit and sensor angles of view, with satellite orbit calculations made to determine the time frame during which the satellite can observe that location. From the results of these calculations, commands are issued with sensor angles of view and time as sensor parameters.
- Data Capacity Management stores the sensor observation data in the satellite's memory and calculates the time to transmit the data to the ground station while the satellite is visible. Since there are restrictions on when data may be transmitted to a ground station and given the limited capacity of the satellite's onboard memory, it schedules data transmission efficiently so that memory does not become full.

3) Production planning technology focusing on general-purpose use: Global Earth Observation Data Processing and Control System for GOSAT (Processing and Control System)

Corrective data and related data are necessary to convert the data measured by sensors mounted on the satellite into meaningful physical quantities for general-purpose use. Such data might not necessarily be received at the same time as the observation data, so there is a need for processing that does not start until all data becomes available. Operation of the Processing and Control System is dependent on data. When observation data is received, it checks to see whether all data required for processing is available and waits for any pending data to arrive. Once all data becomes available, the Processing and Control System activates the Level 1 processing software for processing the observation data, and hands over processing to the processing software. When processing is completed, the Level 1 processing software notifies the Processing and Control system, which then passes the processed data (product) to the EORC information system (EIS) for accumulation and distribution.

Processing and control systems were previously developed for individual satellites, but a more advanced system incorporating a generalized design has been developed for also using the current system for new satellites to be launched by JAXA in the future. This has been achieved by tabulating such parameters as those for data that must wait until all data becomes available to allow processing to start, the duration of a waiting time-out, processing details following a time-out, and the activation of programs required in processing, as well as by creating a cluster configuration that facilities sensor-specific processing on individual computers and allows increases in processing and the flexible accommodation of sensors.

4) System for storing important observation data: EORC Information System (EIS)

GOSAT normally makes 14 or 15 circuits of the earth per day, and the EOC and the Svalbard Station receive the observation data obtained during those orbits. Observations are made virtually every day and the amount of data accumulated during the five years of the satellite's mission will total about 300 TB. To help users efficiently and easily retrieve the data they need from this enormous amount of data, control data indicating the characteristics of observation data, such as the time and location of observation, and the type of data, will also be retained.

EIS also sends and receives important data among such facilities as the EOC, the Svalbard Station, and the Processing and Control System, as well as with NIES and other data users 24 hours a day, 7 days a week, and manages and stores the various types of data that represent valuable assets to the users. The main tasks of EIS are therefore to accumulate important data, transmit it to and receive it from various facilities, and then distribute it to users. FASOL is currently applying its experience in configuring data accumulation and processing systems to the Advanced Land Observing Satellite "Daichi" currently operated by JAXA and other satellites operated in the past, as well as its operational know-how in the development of EIS for which FASOL is responsible. EIS is a system that enables additional satellites to be accommodated through simple procedures. All expansion sections for additional satellites have been parameterized to enable data to be stored for other earth observation satellites to be launched after GOSAT.

## 5. Conclusion

This paper examined the operation of general satellite ground systems, the ground systems for GOSAT, and the major systems developed by Fujitsu. For many years, Fujitsu has provided wide-ranging support, including that based on customer requirement reviews, design, manufacture, testing and operation, for the development of JAXA satellite ground systems, spanning the overall lifecycle from summarizing customer requirements upon a review to actual operation. By applying its know-how accumulated as a result, as well as its software development technologies and computer hardware, Fujitsu has made a major contribution to the development of GOSAT ground systems. We fully intend to continue using such know-how and development technologies for the environment monitoring and disaster monitoring satellites that JAXA plans to launch in the future.

## Acknowledgement

We would like to express our gratitude to the persons concerned at JAXA for their helpful suggestions and advice on the development of ground systems.

### References

1) The Japan Aerospace Exploration Agency: Greenhouse Gases Observing Satellite. *http://www.jaxa.jp/projects/sat/gosat/index_j.html*
2) H. Kitabatake et al.: Orbit Determination of Satellite. (in Japanese), *FUJITSU,* Vol.48, No.1, pp.26-33 (1997).
3) M. Mohara: Space System Overview. (in Japanese) 1st Edition, Tokyo, Baifukan, 1995, pp.217-223.

**Masato Yokomizo**
*Fujitsu Ltd.*
Mr. Yokomizo received the B.S. degree in Geophysics from Hokkaido University in Sapporo, Japan in 1988. He joined Fujitsu Ltd., Tokyo, Japan in 1988, where he has been engaged in the development of spacecraft ground systems. He is also taking part in the development of remote sensing systems.