The GOSAT Project

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National Institute for Environmental Studies (NIES), Japan
Contents

- Status of the GOSAT observations
- TANSO-FTS SWIR CO$_2$ and CH$_4$ Level 2 (V01.xx) data products
- Validation summary and temporal variation of Level 2 (V01.xx) data products
- Collaboration with worldwide researchers

GOSAT (IBUKI) launched by H-IIA F-15 vehicle on January 23, (Photo by Mitsubishi Heavy Industries, LTD)
GOSAT was launched on **23 January 2009** from Tanegashima Island in Japan, and has been operating for more than 3 years.

GOSAT is the first satellite in the world dedicated to observing greenhouse gases.

Researchers worldwide are using GOSAT data.

GOSAT makes measurements globally, particularly over the areas where ground monitoring stations are sparse.

GOSAT data are available from **June 2009**.
Status of the GOSAT observations
TANSO-FTS
(Fourier Transform Spectrometer)

TANSO-FTS

TANSO-CAI

TANSO = Thermal And Near infrared Sensor for carbon Observation

‘TANSO’ also means carbon in Japanese.

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral coverage [μm]</th>
<th>Spectral resolution [cm⁻¹]</th>
<th>Target species</th>
<th>Instantaneous field of view/Field of observation view at nadir</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.758~0.775</td>
<td>0.5</td>
<td>O₂</td>
<td>Instantaneous field of view: 15.8 mrad Field of view for observation (footprint): diameter of app. 10.5 km</td>
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<tr>
<td>2</td>
<td>1.56~1.72</td>
<td>0.27</td>
<td>CO₂ · CH₄</td>
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<tr>
<td>3</td>
<td>1.92~2.08</td>
<td>0.27</td>
<td>CO₂ · H₂O</td>
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<tr>
<td>4</td>
<td>5.56~14.3</td>
<td>0.27</td>
<td>CO₂ · CH₄</td>
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</table>

<table>
<thead>
<tr>
<th>Band</th>
<th>Spectral coverage [μm]</th>
<th>Target substance</th>
<th>Swath [km]</th>
<th>Spatial resolution at nadir [km]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.370~0.390 (0.380)</td>
<td>Cloud, Aerosol</td>
<td>1000</td>
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<tr>
<td>2</td>
<td>0.668~0.688 (0.678)</td>
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<td>1000</td>
<td>0.5</td>
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<tr>
<td>3</td>
<td>0.860~0.880 (0.870)</td>
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<td>1000</td>
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<tr>
<td>4</td>
<td>1.56~1.68 (1.62)</td>
<td></td>
<td>750</td>
<td>1.5</td>
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</table>
**Greenhouse gases Observing Satellite**

**Cloud and Aerosol Scattering >> S**

- **Camera FOV > 30 km**
- **TANSO FTS IFOV = 10.5 km**
- **TANSO CAI IFOV = 0.5, 1.5 km**
- **SWATH = 900 km**

**Cross Track Patterns**

<table>
<thead>
<tr>
<th>Cross Track</th>
<th>X km</th>
<th>Y km</th>
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<td>1</td>
<td>789</td>
<td>90</td>
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<tr>
<td>3</td>
<td>263</td>
<td>283</td>
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<td>5</td>
<td>158</td>
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<td>7</td>
<td>113</td>
<td>115</td>
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<tr>
<td>9</td>
<td>88</td>
<td>86</td>
</tr>
</tbody>
</table>

@Log. & Lat. 30deg

(Courtesy by H. Suto (JAXA))
Status of ground measurements of GHGs

- GHG monitoring stations: 325, CO2 measurement: 214,
- CH4 measurement: 195 as of 7 March 2012

Location map of data-submitting stations
- Ground-based
- Ship
- Aircraft
Status of ground measurements of GHGs

- GHG monitoring stations: 325, CO2 measurement: 214, CH4 measurement: 195 as of 7 March 2012

GHG data are obtained only for cloud-free scenes!
Measurement data numbers and coverage (June 2009 - May 2010) (2.5 deg. mesh)

(by Y. Yoshida (NIES))
TANSO-FTS Level 1B

Wavenumber (cm$^{-1}$)

Radiance (W/m$^2$/micron/str)

Absorption band of water vapor (H$_2$O)
Absorption band of carbon dioxide (CO$_2$)
Absorption band of methane (CH$_4$)
Absorption band of oxygen (O$_2$)
Absorption band of ozone (O$_3$)

Band 1P
Band 1S
Band 2P
Band 2S
Band 3P
Band 3S
Band 4

SWIR
TIR
GOSAT Data Processing Flow

Sensors
- TANSO-FTS (provided by JAXA)
- TANSO-CAI (provided by JAXA)

Observation data
- Interferogram (at the red circle in the below Fig.)
- Radiance distribution (at the first light data over Japan)

Processed Products
- Level 1A
- Spectrum (at the first light data)
- Level 2

Level 1B
- L2 (column abundance obtained by each scan)
- L3 (spatial and temporal average of column abundances)

Level 4A
- 3D distribution of CO$_2$ (Forward model calculation)
- Carbon flux (sources/sinks) (Inverse model calculation)

Level 4B

Ground Monitoring Station Data

Source: NIES GOSAT project pamphlet
# GOSAT Standard Data Products

<table>
<thead>
<tr>
<th>Product Level</th>
<th>Sensor / Band</th>
<th>Product Designation</th>
<th>Description</th>
<th>Product Provision Unit</th>
<th>Data Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1B</td>
<td>FTS</td>
<td>FTS L1B data</td>
<td>Radiance spectral data obtained by performing Fourier transform on interferogram data</td>
<td>per FTS scene</td>
<td>HDF5</td>
</tr>
<tr>
<td></td>
<td>CAI</td>
<td>CAI L1B data</td>
<td>Radiance data (band-to-band and geometric corrections applied / data mapping not performed)</td>
<td>per CAI frame</td>
<td></td>
</tr>
<tr>
<td>L1B+</td>
<td>CAI</td>
<td>CAI L1B+ data</td>
<td>Radiance data (band-to-band and geometric corrections applied / data mapping performed)</td>
<td>per CAI frame</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>FTS SWIR</td>
<td>L2 CO₂ column amount (SWIR)</td>
<td>CO₂ column abundance data retrieved from SWIR radiance spectral data</td>
<td>can be selected</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L2 CH₄ column amount (SWIR)</td>
<td>CH₄ column abundance data retrieved from SWIR radiance spectral data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FTS TIR</td>
<td>L2 CO₂ profile (TIR)</td>
<td>CO₂ vertical profile data retrieved from TIR radiance spectral data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L2 CH₄ profile (TIR)</td>
<td>CH₄ vertical profile data retrieved from TIR radiance spectral data</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAI</td>
<td>L2 cloud flag</td>
<td>Cloud coverage data</td>
<td>per CAI frame</td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>FTS SWIR</td>
<td>L3 global CO₂ distribution (SWIR)</td>
<td>CO₂ column-averaged mixing ratio data projected on a global map</td>
<td>per month (global)</td>
<td>HDF5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L3 global CH₄ distribution (SWIR)</td>
<td>CH₄ column-averaged mixing ratio data projected on a global map</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>FTS TIR</td>
<td>L3 global CO₂ distribution (TIR)</td>
<td>Monthly-averaged CO₂ concentration at each vertical level projected on a global map</td>
<td>per month (global)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L3 global CH₄ distribution (TIR)</td>
<td>Monthly-averaged CH₄ concentration at each vertical level projected on a global map</td>
<td>per month (global)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAI</td>
<td>L3 global radiance distribution</td>
<td>Global radiance distribution data (3 days worth, including data for cloudy segments)</td>
<td>per 3 days (global)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>CAI</td>
<td>L3 global reflectance distribution (clear sky)</td>
<td>Clear-sky radiance data (composed only of clear-sky segments selected from a month worth of data)</td>
<td>per 15 days 30° × 60° (lat. × lon.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>L3 global NDVI</td>
<td>Vegetation index global distribution data (cloudy segments excluded)</td>
<td>per 15 days 30° × 60° (lat. × lon.)</td>
<td></td>
</tr>
<tr>
<td>L4A</td>
<td></td>
<td>L4A global CO₂ flux</td>
<td>CO₂ flux per each of the 64-divided global regions (monthly average)</td>
<td>per year (64 regions)</td>
<td>Text</td>
</tr>
<tr>
<td>L4B</td>
<td></td>
<td>L4B global CO₂ distribution</td>
<td>Three-dimensional, global distribution of CO₂ concentration</td>
<td>per month 2.5° × 2.5° grid (lat. × lon.)</td>
<td>NetCDF</td>
</tr>
</tbody>
</table>
TANSO-FTS SWIR CO₂ and CH₄ Level 2 (V01.xx) data products
TANSO-FTS SWIR Level 2 & Level 3
Annual Change of XCO₂
(October 2009, 2010, 2011)

XCO₂

Level 2

Level 3

Oct. 2009

Oct. 2010

Oct. 2011
TANSO-FTS SWIR Level 2 & Level 3
Annual Change of XCH$_4$
(October 2009, 2010, 2011)
GIF Animation of Monthly Level 2 of XCO$_2$ and XCH$_4$

(2.5 deg. mesh, June 2009 – December 2010)

XCO$_2$  XCH$_4$

2009.06  2009.06
GIF Animation of Monthly Level 3 of XCO$_2$ and XCH$_4$

(2.5 deg. mesh, April 2009 – February 2011)
(for 22 months except for May 2009)

Available from “Gallery” page of  http://data.gosat.nies.go.jp/
Greenhouse Gas Monitoring From Space by GOSAT

Monthly global map of the CO₂ column-averaged volume mixing ratios in four seasons for three years (April 2009 - July 2011)

2009
Apr.
Jul.
Oct.

2010
Jan.
Apr.
Jul.
Oct.

2011
Jan.
Apr.
Jul.
Oct.

(Biases of the GOSAT XCO₂ data about 9 ppm lower than the ground-based validation data are not corrected in these figures.)

(Japan exhibition booth @ COP17)
Validation summary
Schematic illustration of validation experiments

Source: GOSAT Project pamphlet
TCCON sites for GOSAT validation

TCCON: Total Carbon Column Observing Network
(https://tccon-wiki.caltech.edu/)
XCO$_2$ and XCH$_4$ comparing TCCON FTS sites & GOSAT

**CO$_2$**

- FTS: +/- 0.5 hr
- GOSAT: 1~3 deg
- Number: 62
- Bias, STD: [-8.85, 4.75] ppm

**CO$_2$**

- FTS: +/- 1 hr
- GOSAT: +/- 2 deg
- Number: 256
- Bias, STD: [-8.57, 4.44] ppm

**CO$_2$**

- FTS: +/- 1 hr
- GOSAT: +/- 5 deg
- Number: 966
- Bias, STD: [-8.25, 3.97] ppm

**CH$_4$**

- FTS: +/- 0.5 hr
- GOSAT: 1~3 deg
- Number: 62
- Bias, STD: [-20.4, 18.9] ppb

**CH$_4$**

- FTS: +/- 1 hr
- GOSAT: +/- 2 deg
- Number: 256
- Bias, STD: [-15.8, 22.3] ppb

**CH$_4$**

- FTS: +/- 1 hr
- GOSAT: +/- 5 deg
- Number: 966
- Bias, STD: [-14.8, 22.6] ppb

y = x + b

Bias, STD: [-8.85, 4.75] ppm

Coincidence Condition:

- FTS: +/- 0.5 hr
- GOSAT: 1~3 deg
- Number: 62

Bias, STD: [-20.4, 18.9] ppb

(by Morino @ IWGGMS-7 (2011))
Validation Summary

TANSO-FTS SWIR Level 2 (V01.xx)
(validated by comparing with ground-based TCCON FTS)

<table>
<thead>
<tr>
<th></th>
<th>Bias</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(X_{\text{CO2}})</td>
<td>-8.85 ppm (-2.3 %)</td>
<td>4.75 ppm (1.2 %)</td>
</tr>
<tr>
<td>(X_{\text{CH4}})</td>
<td>-20.4 ppb (-1.2 %)</td>
<td>18.9 ppb (1.1 %)</td>
</tr>
</tbody>
</table>

(by Morino et al., Atmos. Meas. Tech., 4, 1061–1076, 2011)
Collaboration with TCCON sites for GOSAT Validation

- NIIES has contracted with the following universities/institutes for the research support and/or technical assistance in order to obtain TCCCON ground-based FTSs data in sync with GOSAT observations over the sites.
  - U. Bremen (Germany): Bremen, Bialystok, Orleans, Spitsbergen
  - Caltech (USA): Park Falls, Lamont
  - U. Wollongong (Australia): Darwin, Wollongong
  - NIWA (New Zealand): Lauder
Aircraft measurements by JAL, NOAA, and NIES
(by I. Morino & O. Uchino)

about 40-50 sites in the world

CONTRAIL data (so called JAL data) for CO₂
NOAA aircraft sampling data for CH₄
NIES aircraft sampling data for CO₂ and CH₄
2007-2010


Uncertainty of XCO₂ from profile: ~ 1 ppm

CONTRAIL: in situ CO₂ measurements
NOAA, NIES: flask sampling

CONTRAIL Project
(Comprehensive Observation Network for TRace gases by AirLiner)
Validation by Using Aircraft Measurement Data

- Using CONTRAIL & NOAA Data
- Coincidence: ±2 deg. (Long. & Lat.)

\[
y = x + b
\]

**GOSAT CO2 (ppm)**

- Data Number: 548
- Bias: -8.3 ppm
- STD: 4.4 ppm

**GOSAT CH4 (ppm)**

- Data Number: 926
- Bias: -0.6 ppb
- STD: 20 ppb

(by I. Morino & O. Uchino)

Solid line: one-to-one
Dashed line: Regression line as

\[
y = X + b
\]
## Validation Summary

TANSO-FTS SWIR Level 2 (V01.xx)
(validated by comparing with ground-based TCCON FTS)

<table>
<thead>
<tr>
<th></th>
<th>Bias</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{CO2}$</td>
<td>-8.85 (-8.3) ppm  (-2.3 %)</td>
<td>4.75 (4.4) ppm  (1.2 %)</td>
</tr>
<tr>
<td>$X_{CH4}$</td>
<td>-20.4 (-0.6) ppb (-1.2 %)</td>
<td>18.9 (20) ppb  (1.1 %)</td>
</tr>
</tbody>
</table>

(by Morino et al., Atmos. Meas. Tech., 4, 1061–1076, 2011)

( ) by using Aircraft measurement data
Illustration of how light scattering would impact data processing

(Major error sources: cirrus & aerosols) (by S. Oshchepkov & A. Bril (NIES))

The light path can be modified by two mechanisms:

One is direct scattering of sunlight from the cloud to the satellite

The other mechanism is due to multiple light reflections between the cloud and the ground surface

This effect is predominant for dark surface such as ocean and leads to underestimation of gas amount

This effect holds for bright surface like over desert and leads to overestimation of gas amount
Temporal variation of Level 2 (V01.xx)
Temporal & latitudinal variation

**CO₂**

(for all data)

(by Y. Yoshida (NIES))

**CH₄**

(by Y. Yoshida (NIES))
Temporal variation of zonal mean, comparing with NIES TM (for all data)

(by Y. Yoshida (NIES))
Preliminary results of SWIR L2 V02
Preliminary results of SWIR L2 V02

(by Y. Yoshida (NIES))
GOSAT contribution to carbon flux estimation

Inversion of atmospheric transport model

GHG Observations

Ground Monitoring Stations

Estimation of Global Carbon Flux Distribution

IBUKI (GOSAT) (launched in Jan. 2009)

Altitude 666 km

Solar Radiation

IFOV: 10 km Ø

GHG data by IBUKI
Monthly CO₂ Flux Estimates

64-regional monthly CO₂ fluxes estimated from ground-based network data* and GOSAT XCO₂ retrievals (currently under evaluation). Results for four months (July 2009, October 2009, January 2010, and April 2010) are presented.


GOSAT websites
JAXA GOSAT project http://www.jaxa.jp/projects/sat/gosat/index_e.html
NIES GOSAT Project http://www.gosat.nies.go.jp/index_e.html
Collaboration with worldwide researchers
GOSAT Research Promotion

Research Announcement

Research Topics
1) Calibration
2) Data Processing Algorithm
3) Validation
4) Carbon Balance Estimation and Atmospheric Transport Models
5) Data application

The 1st GOSAT RA in 2008
52 research themes were selected.

The 2nd GOSAT RA in 2009
36 research themes were selected.

The 3rd GOSAT RA in 2010
18 research themes were selected.

Data Release

CAI & FTS-L1B data product: October 30, 2009
CAI & FTS-L2 data product: February 18, 2010
Improved FTS-L2 data product: August 24, 2010
### Countries of GOSAT RA PI's

<table>
<thead>
<tr>
<th>Country</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>Total</th>
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<tbody>
<tr>
<td>Japan</td>
<td>23</td>
<td>8</td>
<td>1</td>
<td>32</td>
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<tr>
<td>USA</td>
<td>7</td>
<td>8</td>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>Canada</td>
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</tr>
<tr>
<td>UK</td>
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<td>3</td>
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<td>5</td>
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<td>France</td>
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<td><strong>Total</strong></td>
<td><strong>52</strong></td>
<td><strong>36</strong></td>
<td><strong>18</strong></td>
<td><strong>106</strong></td>
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NIES GOSAT Project Web site

http://www.gosat.nies.go.jp/index_e.html
Concluding Remarks

- GOSAT has continued observations more than 2 years and 9 month since June 2009.

- Biases of GOSAT TANSO-FTS SWIR Level 2 data product (V01.xx) are $X_{\text{CO}_2} : -2 \sim -3\%$ and $X_{\text{CH}_4}: \sim1\%$. Standard deviations of them are $\sim1\%$.
  - The L2 algorithm will be revised into V02.xx soon.

- GOSAT data have been used by worldwide researchers. We are collaborating on Cal/Val, retrieval, carbon source/sink estimation, and scientific data use.

- GOSAT project has continued collaborating with alliance organizations (AO1: JMA, NASA, ESA, CNES, ECMWF, …)