GOSAT Data Products Generated in Collaborative Effort with NOAA/GMD


*National Institute for Environmental Studies (NIES), Japan
### TANSO onboard GOSAT

<table>
<thead>
<tr>
<th>Size</th>
<th>Main body</th>
<th>3.7 m x 1.8 m x 2.0 m (Wing Span 13.7m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass</td>
<td>Total</td>
<td>1750kg</td>
</tr>
<tr>
<td>Power</td>
<td>Total</td>
<td>3.8 KW (EOL)</td>
</tr>
<tr>
<td>Life Time</td>
<td></td>
<td>5 years</td>
</tr>
<tr>
<td>Orbit</td>
<td></td>
<td>sun synchronous orbit</td>
</tr>
<tr>
<td></td>
<td>Local time</td>
<td>13:00+/-.0:15</td>
</tr>
<tr>
<td></td>
<td>Altitude</td>
<td>666km</td>
</tr>
<tr>
<td></td>
<td>Inclination</td>
<td>98deg</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>3 days</td>
</tr>
<tr>
<td>Launch</td>
<td>Vehicle</td>
<td>H-IIA</td>
</tr>
<tr>
<td></td>
<td>Schedule</td>
<td>Jan. 23 2009</td>
</tr>
</tbody>
</table>

TANSO = Thermal And Near infrared Sensor for carbon Observation

TANSO (炭素) = Carbon

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**TANSO-FTS (Fourier Transform Spectrometer)**
- SWIR reflected on the earth’s surface
- TIR radiated from the ground and the atmosphere

**TANSO-CAI (Cloud and Aerosol Imager)**
- Ultraviolet (UV) (0.38 micron),
- visible (0.67 micron),
- NIR (0.87 micron), and SWIR (1.6 micron)

(Courtesy of JAXA)
Objectives of the GOSAT Project

1. To obtain the global distributions of greenhouse gas (GHG) concentrations (CO₂ and CH₄) and their temporal variations
   - To visualize changing GHG global distributions
   - To fill out the gaps in the network of ground monitoring stations

2. To improve accuracy (decrease uncertainty) of the carbon flux (net sources and sinks) estimation on a sub-continental scale

3. To develop technologies for future GHG observing satellite ⇒ GOSAT-2
• **GOSAT** was launched on January 23, 2009 and has been in operation for more than five years.

• **GOSAT** observations successfully filled out the gaps in the ground-based monitoring network, except for around the equator and the high-latitude regions.

• Uncertainties in monthly regional flux estimates of CO₂ and CH₄ have been decreased by using **GOSAT** data.
Records of the GOSAT Observation
Locations for Valid Data Retrieved

Locations of GHG monitoring stations
(from WDCGG, as of May. 11, 2015)
Total: **330**
CO₂ measurement: **226**
CH₄ measurement: **213**

The number of **GOSAT** Level2 (Ver. 2) XCO₂ data in a year (2009.6-2010.5).
Red-white: 200 – 1000 data/year
Green-orange: 20 – 100 data/year
Blue: 0 – 10 data/year

Satellites can fill the gaps in the ground-based monitoring network with several exceptions.
55-month-long GOSAT XCO₂ and XCH₄
(June 2009 – December 2013)

- Above movies are 1-month-moving average GOSAT XCO₂ and XCH₄ with three-day interval. The mesh size is 2.5 degree.

- Various interesting features are shown in these movies such as annual and seasonal variations of XCO₂ and localized anomalies of XCH₄.

- GOSAT obtained XCO₂ and XCH₄ data for more than 6 years. Validation results suggest that relative accuracies (variations) of XCO₂ and XCH₄ are ≈ 2 ppm (≈ 0.5%) and 12 ppb (≈ 0.7%), respectively.
A worldwide network of ground-based FTS (TCCON; over 20 sites in the world)

Morino et al. (2011, AMT)
Yoshida et al. (2013, AMT)
Observation sites used in this study

- CONTRAIL data (Machida et al., 2008): 20 sites (2007 - 2010)
- NOAA/DOE data: 17 sites (2007 - 2011)
- NIES data: 4 sites (2008 - 2010)
- HIPPO data: 5-6 sites (2009 - 2010)
- NIES-JAXA campaign data: 1 site (2010)

Measurement uncertainty in CO₂ ~ 0.2 ppm
Uncertainty in calculating XCO₂ ~ 1 ppm

A paper for basic parts on profiles to derive X: Araki et al. (2010, ACP)
Miyamoto et al. (2013, ACP)

Measurement uncertainty in CH₄ ~ 2 ppb
Uncertainty in calculating XCH₄ ~ 15 ppb

CONTRAIL: continuous measurements
NOAA, DOE, NIES, NIES-JAXA: Flask sampling

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**XCO₂ and XCH₄ calculation from aircraft data**

Stratospheric and mesospheric profile
For XCO₂, ACTM* model outputs (Patra et al., 2009) were used. For XCH₄, Atmospheric Chemistry Experiment (ACE, Jones et al., 2011) and Halogen Occultation Experiment (HALOE, Grooß and Russell, 2005) are used.

Below tropopause
If observing range below tropopause, the value measured at highest altitude was extended to the tropopause.

Near the surface
Complemented by meteorological tower data or extrapolated as a constant value to ground.

\[
XCO₂ = \frac{\sum_{0 \text{ km}}^{85 \text{ km}} [CO₂]^{(i)} × N_{air}^{(i)}}{\sum_{0 \text{ km}}^{85 \text{ km}} N_{air}^{(i)}} \\
XCH₄ = \frac{\sum_{0 \text{ km}}^{85 \text{ km}} [CH₄]^{(i)} × N_{air}^{(i)}}{\sum_{0 \text{ km}}^{85 \text{ km}} N_{air}^{(i)}}
\]

\([CO₂]^{(i)}\): CO₂ ratio of \(i\)-th layer  
\([CH₄]^{(i)}\): CH₄ ratio of \(i\)-th layer  
\(N_{air}^{(i)}\): Dry air number density of \(i\)-th layer

*ACTM: AGCM-based Chemistry Transport Model  
(by I. Morino & O. Uchino (NIES))

Miyamoto et al. (2013, ACP); Inoue et al. (2014, AMT)
GOSAT vs Aircraft
(by I. Morino & O. Uchino (NIES))

**GOSAT XCO₂ (ppm)**

- **Land:** 74
  - -0.68 ± 2.56 ppm
  - r = 0.85

- **Ocean:** 11
  - -1.82 ± 1.04 ppm
  - r = 0.96

**Aircraft XCO₂ (ppm)**

- **Land:** 182
  - -0.99 ± 2.51 ppm
  - r = 0.86

- **Ocean:** 40
  - -2.27 ± 1.79 ppm
  - r = 0.82

**GOSAT XCH₄ (ppb)**

- **Land:** 43
  - 1.5 ± 14.9 ppb
  - r = 0.61

- **Ocean:** 3
  - 4.1 ± 9.4 ppb

**Aircraft XCH₄ (ppb)**

- **Land:** 102
  - 2.0 ± 16.0 ppb
  - r = 0.93

- **Ocean:** 10
  - 6.5 ± 8.8 ppb

Inoue et al. (2013, ACP)
Inoue et al. (2014, AMT)

(XCO₂)
(XCH₄)
Contribution of satellite data to carbon flux
Input to GOSAT Level 4 regional flux estimation (CO$_2$ v02.03 released in Jan. 2015)

GOSAT Level 2 X$_{CO2}$ v02.11

GLOBALVIEW-CO2 2013 (GV)

Biases were corrected based on validation result

$X_{CO2}$ retrievals were gridded to $5^\circ \times 5^\circ$ cells and monthly-averaged

Cells with N<3 per month were not used

Combined

Data from 212 sites were monthly-averaged

GOSAT $X_{CO2}$ retrievals compliment GV data

Input to inverse modeling
Monthly CO₂ Flux Estimates and Uncertainties

July 2010  
July 2011  
July 2012

Top: monthly-mean CO₂ data (input to flux estimation)  
Squares: GOSAT XCO₂ gridded to 5° × 5° cells  
Circles: GLOBALVIEW data (212 sites)  

Bottom: Flux uncertainty  

(by H. Takagi (NIES))
Time series of monthly regional flux estimates

Upper
Green: Prior estimate
Red: Posterior estimate by GV only
Blue: Posterior estimate by GV + GOSAT
Unit: gC m⁻² day⁻¹
Gray bar: Flux uncertainty reduction (%)

Lower
Red: Flux unc. (GV-only estimate)
Blue: Flux unc. (GV + GOSAT estimate)

(by H. Takagi (NIES))
GOSAT CH$_4$ inverse modeling, H. Kim & S. Maksyutov, NIES

Interannually varying monthly CH$_4$ emissions
1) Anthropogenic sources by EDGAR v4.2
2) Wetlands, rice paddies and soil sinks by VISIT (Ito and Inatomi, 2011)
   Termites by GISS (Fung et al. 1991)
3) Biomass burning by GFED (van der Werf et al. 2010)

NIES transport model (NIES08)
2.5° by 2.5°, 32 vertical layers
6-hourly JCDAS
photochemical loss of CH$_4$ (TC-CH$_4$) (Belikov et al., 2012)

Inverse model (Fixed-lag Kalman smoother)

\[
\begin{align*}
    L_s &= (z - Hs)^T R^{-1} (z - Hs) + (s - s_p)^T Q^{-1} (s - s_p) : \text{cost function} \\
    s' &= s_p + QH^T (R + HQH^T)^{-1} (z - HS_p) \\
    Q' &= Q - QH^T (R + HQH^T)^{-1} HQ
\end{align*}
\]

H : basis functions
v : data uncertainty
R : data uncertainty covariance
z : model-observation mismatch
s : source strengths to be estimated
s$_p$ : the priori source
Q : the prior flux uncertainty covariance

Background states
anthropo. wetlands, rice, soils, termites
biomass burning

Basis functions (43reg $\times$ 3cat $\times$ 4mon)

The World Data Centre for Greenhouse Gases (WDCGG)

cf). GOSAT L4 CH$_4$ product release note (http://data.gosat.nies.go.jp)
Location of CH$_4$ measurement sites used in GOSAT L4 CH$_4$ (v01.02)

We are using CH$_4$ monitoring data via the World Data Centre for Greenhouse Gases (WDCGG) site. Many of them are originated from the NOAA ESRL/GMD.
Monthly $\text{CH}_4$ Flux Estimates and Uncertainties

January 2010

January 2011

January 2012

**Top:** monthly-mean GOSAT XCH$_4$ data gridded to 2.5º × 2.5º mesh (input to flux estimation)

**Middle:** Monthly flux estimates (GOSAT Level 4A CH$_4$)

**Bottom:** Flux uncertainty

* Anthropogenic, natural, and biomass burning emissions are estimated separately for each region.
Concluding Remarks

◆ GOSAT Project has released almost all of its standard data products to registered researchers and the general public.

◆ The GOSAT Level 2 XCO₂ and XCH₄ data products have been validated with TCCON FTS data, NOAA and DOE airborne data, CONTRAIL data, and other reference data.

◆ The Level 4A CO₂ and CH₄ data product (monthly regional source-sink estimates) have been generated with GOSAT Level 2 data, selected GlobalView data, and NOAA ESRL/GMD observational data provided via the WDCGG.

◆ In this way, the six-year-long GHG observation by GOSAT have been performed by collaborative effort with the ESRL/GMD groups in data validation and surface flux estimation. We express special thanks to the NOAA ESRL/GMD members.