Model application of GOSAT data: Level 4 data products

Level 4 products consist of Level 4A and Level 4B products. Level 4A product is a dataset of net monthly CO$_2$ and CH$_4$ flux estimated for subcontinental regions (several thousand kilometers in perimeter) of the world. The region numbers are 64 for CO$_2$ and 43 for CH$_4$. Level 4B product presents global three-dimensional CO$_2$ and CH$_4$ distributions simulated with an atmospheric tracer transport model and the CO$_2$ and CH$_4$ flux estimates. These products were made available to the general public.

Global monthly CO$_2$ and CH$_4$ flux values (Level 4A) and 3-dimensional concentrations (Level 4B)

The estimation process is twofold. First, values of ground-based and GOSAT-based GHG concentrations are predicted by performing simulations of atmospheric GHG transport. The transport simulations use a priori GHG flux data as input values. These input data consist of anthropogenic emission data, wildfire emission data, and model estimates of GHG exchange between the terrestrial biosphere and the atmosphere, and between the ocean and the atmosphere. Second, the predicted GHG concentrations are matched to the observed values by adjusting the a priori GHG fluxes used in the GHG concentration simulation. In the CO$_2$ flux estimation, the adjustment is performed only on the terrestrial and oceanic exchanges. In the CH$_4$ flux estimation, the adjustment is performed on all of the input data.

In the case of CO$_2$, many regions in the Northern Hemisphere are net sinks (absorbers) in summer but net sources (emitters) in winter (Figure 8). Level 4B product is the result of atmospheric GHG transport simulation based on the flux distribution estimated from the ground-based and GOSAT based concentration data. Level 4B product stores global concentrations in every 2.5° mesh in intervals of six hours at 17 vertical levels ranging from near the surface to the top of the atmosphere. The three-dimensional GHG distributions for each level and period (L4B maps) are shown at https://data2.gosat.nies.go.jp/index_en.html (“Gallery” – “L4B”).

The column-averaged dry-air mole fraction is the ratio of the total amount of a gas species to the total amount of dry air contained in a vertical column from the ground surface to the top of the atmosphere. The Greenhouse gases Observing SATellite, GOSAT (nicknamed IBUKI), was successfully launched on January 23, 2009, and has been collecting data globally under cloud-free conditions for estimating the column-averaged dry-air mole fractions* of major greenhouse gases such as carbon dioxide (CO$_2$) and methane (CH$_4$). For data quality improvement, we updated our algorithm used for the estimation of XCO$_2$** and XCH$_4$***, and validated the retrieved values by comparing them to high-precision ground-based measurements. These validated values have been distributed to researchers and the general public as version 2 of GOSAT Level 2 product. The latest data have been processed using the algorithm (Version 2).

Using the Level 2 products, higher-level products such as the monthly estimates of CO$_2$ and CH$_4$ regional fluxes were obtained. Also based on these flux estimates, concentrations of CO$_2$ and CH$_4$ in 3-dimensional space were simulated. These data have been made available to the general public as GOSAT Level 4A (flux) and 4B (3-dimensional concentration distributions) products.

We estimated anthropogenic CO$_2$ concentrations in the Tokyo metropolitan area in addition to other megacities in the world, based on GOSAT data collected over the megacities and their surroundings for the five and half years from June 2009 through December 2014. The CO$_2$ concentrations in Japan using GOSAT measurements were found to be generally consistent with those estimated from CO$_2$ emission inventories based on statistics by comparing the two estimates. This result suggests that GOSAT-like space-based observations potentially enable us to monitor and verify the CO$_2$ emissions that all nations are required to report under the Paris Agreement. With the progress in the satellite data accumulation and further improvement in the analysis methods, these observational data from GOSAT and its successor under development (GOSAT-2) will be compared with emissions inventories.
Seasonal variations and annual trends of greenhouse gas concentrations

**GOSAT** data, collected and archived since 2009, can be used to map the seasonal variations and annual trends of XCO₂ and XCH₄ on regional and global scales. Maps of monthly averaged values of XCO₂ (Version 2) for four selected months in 2015-16 period are shown in Figure 4 (inset color scale shows that XCO₂ value changes from blue-low to red-high). The map for July shows that the average value of XCO₂ for higher latitudes in the Northern Hemisphere during summer is low because of the active photosynthesis of vegetation during that time. In January and April, the average value of XCO₂ in the Northern Hemisphere is higher than in the Southern Hemisphere.

Figure 5 shows maps of monthly averages of XCO₂ for July in the years 2009 to 2016 (excluding 2013). Comparison of the maps reveals both regional differences and an increasing trend in XCO₂ in these years. *Seasons shown below in brown italics are those of the Northern Hemisphere.

**Validation of GOSAT data against ground-based reference**

Before use in scientific research, uncertainties (bias and precision) of Level 2 concentration values must be revealed. GOSAT data validation is performed by using reference data collected from ground-based high-resolution Fourier transform spectrometers (FTSs) developed in the Total Carbon Column Observing Network (TCCON, https://tccon-wikicaltech.edu/) and also from airborne measurements. Figure 7 shows a result of data validation in which GOSAT Level 2 XCO₂, XCH₄, and XH₂O values were compared against the TCCON data. The bias and precision for both XCO₂ and XCH₄ were found to be less than 1% of the concentration values. GOSAT Level 2 data were found to be consistent with the TCCON data. As for XH₂O, the bias was found to be several % and precision about 20%. These results are acceptable as its spatial and temporal variations are large. (**Present -0.5 and ±2.2 ppm for XCO₂, -4 and ±13 ppb*** for XCH₄, and -129 and ±433 ppm for XH₂O respectively)** ***1 ppb = 1/1000 ppm

Figure 7 shows a result of data validation in which GOSAT Level 2 products (Version 2) validated with TCCON data. The period of validation was from April 2009 to December 2016. TCCON data were averaged within 30 minutes before/after the overpasses time of GOSAT. GOSAT data were selected within the square land area of 4 degrees centering each TCCON site. The dashed line represents y=x (one to one), and the blue line is a regression line for y=x+b, where b is the bias. (Left: XCO₂, Middle: XCH₄, Right: XH₂O)