

# **"IBUKI" (GOSAT) Satellite's Historically Unprecedented Observation of Anthropogenic CO<sub>2</sub> Emissions of Mega-City Regions from Space**

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*The Greenhouse gases Observing SATellite "IBUKI", developed jointly by the Ministry of the Environment (MOE), the National Institute for Environmental Studies (NIES), and the Japan Aerospace Exploration Agency (JAXA) is the world's only satellite designed specifically to monitor greenhouse gases from space. The satellite has continued to fulfill its main mission in monitoring atmospheric carbon dioxide (CO<sub>2</sub>) and methane concentrations from space to improve the accuracy of sink/source estimates, and achieve its target to contribute to precision refinement for the ongoing elucidation of carbon cycles, since its launch on January 23, 2009.*

*CO<sub>2</sub> concentrations in mega-cities and their surroundings were analyzed for the three and half years from June 2009 to December 2012, based on the observational data acquired by "IBUKI", indicating the tendency for higher CO<sub>2</sub> concentrations in mega-cities than those in their surroundings. Furthermore, positive correlations were shown between differences in CO<sub>2</sub> concentrations and the concentrations estimated from data for fossil fuel consumption. These results indicate that "IBUKI" observations have the potential to enable us to detect enhanced CO<sub>2</sub> concentrations with their origin in fossil fuel consumption for mega-cities. These studies demonstrate the potential utility of satellite observation of CO<sub>2</sub> concentrations as a tool for monitoring greenhouse gas emissions (inventory) from fossil fuels.*

*With the progress in studies to monitor large point CO<sub>2</sub> sources by satellite observation and other methods, these results will be applied to current and forthcoming research projects involving "IBUKI" and its successor - GOSAT-2 - to be launched in 2018.*

## **1. Overview of the data on anthropogenic CO<sub>2</sub> concentrations from "IBUKI" (GOSAT)**

Carbon dioxide (CO<sub>2</sub>) is a greenhouse gas the atmospheric concentration of which has increased by 40% when compared to pre-industrial times, as a result of anthropogenic activities. Fossil fuel consumption in large fossil fuel power plants and mega-cities are assumed to be the main sources of anthropogenic CO<sub>2</sub> emissions. The CO<sub>2</sub> emission rates in these areas should be accurately evaluated to monitor greenhouse gas emissions.

A validation study has shown that the greenhouse gases observation sensor, "TANSO-FTS" onboard "IBUKI" observes column-averaged CO<sub>2</sub> concentrations (hereinafter, "CO<sub>2</sub> concentrations") to a precision (random error) of 0.5% (approximately 2 ppm) in comparison to the data acquired from ground-based observations. This study investigated the detectability of enhanced CO<sub>2</sub> concentrations due to anthropogenic emissions, by satellite observation.

CO<sub>2</sub> concentrations acquired by "IBUKI" comprise not only those pertaining to anthropogenic emissions but also encompass photosynthetic uptake and respiration-release by plants; emissions due to forest fires; and sink/source by ocean. These processes should be

considered when interpreting the information on anthropogenic CO<sub>2</sub> emissions from the CO<sub>2</sub> concentrations acquired by “*IBUKI*”. This study estimated CO<sub>2</sub> concentrations due to anthropogenic activities from observational data by “*IBUKI*” by the method described below.

Firstly, the spatiotemporal distribution of CO<sub>2</sub> concentrations originating from anthropogenic CO<sub>2</sub> emissions are estimated using the data for anthropogenic CO<sub>2</sub> emission rates from fossil fuel consumption (emission inventory) - a value based on the data for nighttime lights on the earth’s surface as observed by satellite, as well as the information from the database for fossil fuel power plants and an atmospheric tracer transport model. Subsequently, on the basis of this estimate, the observational data for CO<sub>2</sub> concentrations acquired by “*IBUKI*” are classified into two categories: data including contamination by anthropogenic CO<sub>2</sub> emissions (top panel in Figure 1) and those not including this contamination. The individual observational data sets including anthropogenic contamination are subtracted using averaged values for the data not including contamination, and values for CO<sub>2</sub> concentrations from forest fires and plant activities are then subtracted from the data. These calculations produce the figures for anthropogenic CO<sub>2</sub> concentrations using observational data from “*IBUKI*” (bottom panel in Figure 1).

## 2. Results of anthropogenic CO<sub>2</sub> concentration estimates from “IBUKI”

Figure 1 shows global distribution of anthropogenic CO<sub>2</sub> concentrations estimated from observational data from “IBUKI”. Data including contamination by anthropogenic CO<sub>2</sub> emissions is mainly concentrated on the Northern Hemisphere, especially in mega-city regions (top panel in Figure 1).

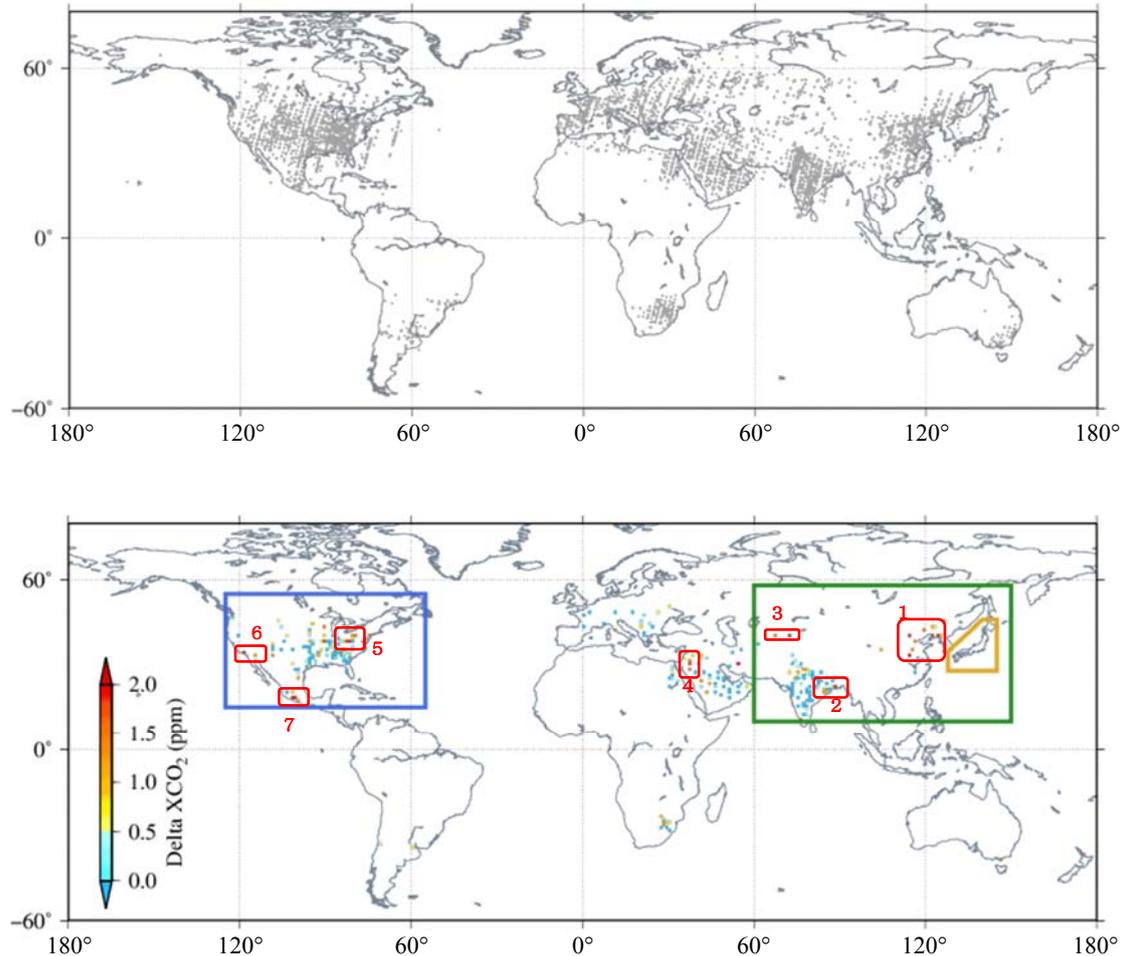


Figure 1 (top) Observational points of “IBUKI” where anthropogenic CO<sub>2</sub> concentrations are higher than 0.1 ppm for June 2009 and December 2012.

(bottom) Distribution of anthropogenic CO<sub>2</sub> concentrations estimated from observational data acquired by “IBUKI” (1 deg. grid resolution; only grid with observational data greater than 24 are plotted). Anthropogenic CO<sub>2</sub> concentrations are shown by colors. Red rectangles show the areas listed in Table 1. Three of four regions used in Figure 3 are shown in yellow, green, and blue for, respectively, Japan, East Asia, and North America.

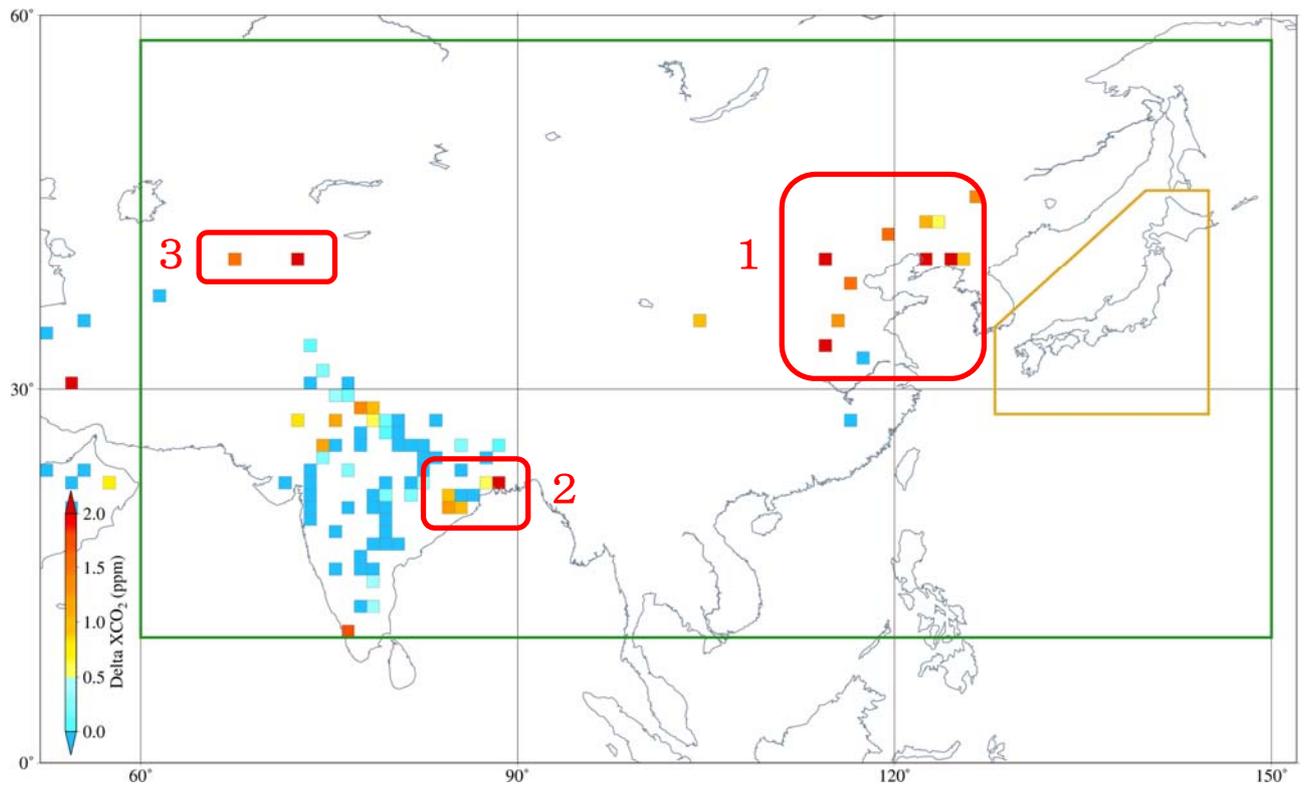
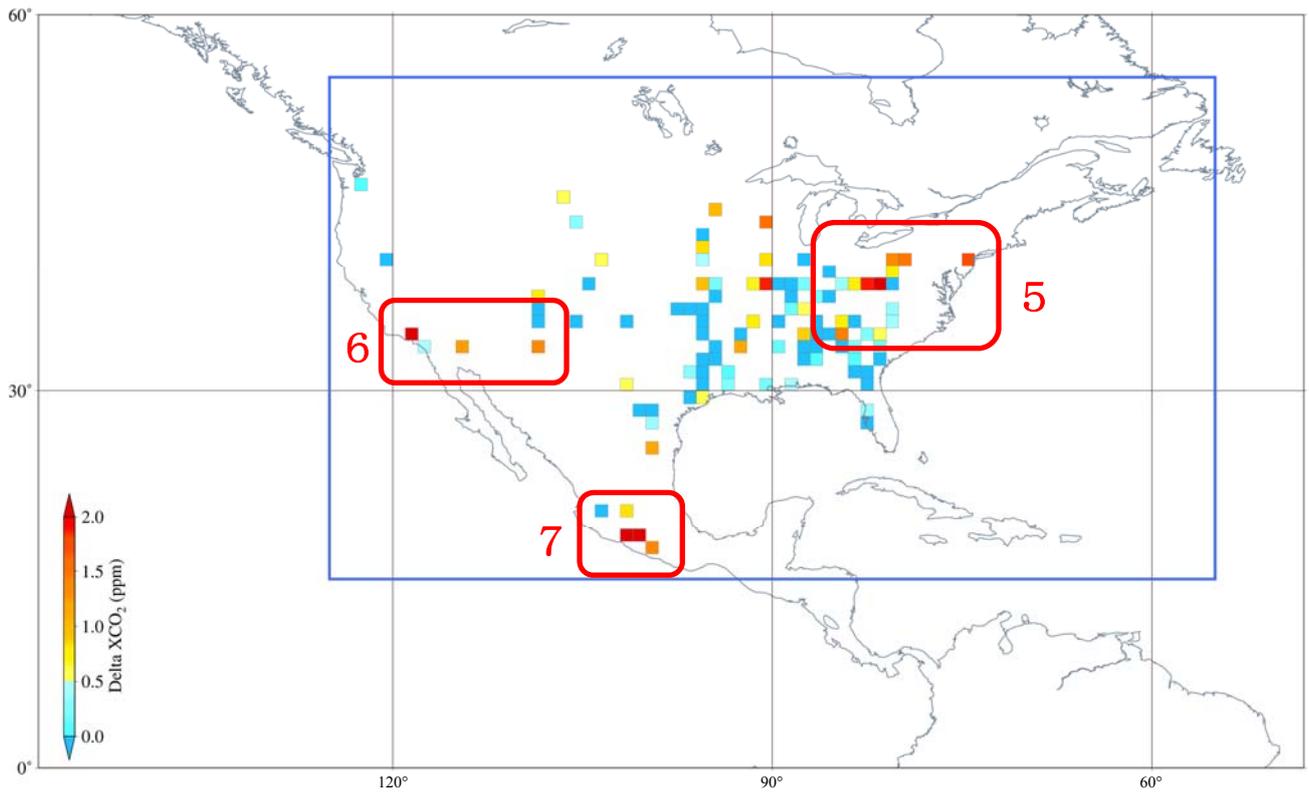


Figure 2 Enlarged views of North America (top) and East Asia (bottom) in Figure 1.

Table 1 A list of regions indicating high concentrations of anthropogenic CO<sub>2</sub> emissions derived from “*IBUKI*” in Figure 1.

No. on Figure 1	Rough range of the region for high concentrations of anthropogenic CO <sub>2</sub> emissions derived from “ <i>IBUKI</i> ”	Countries, regions or major cities in the region	Maximum value of the concentrations of anthropogenic CO <sub>2</sub> emissions for the region (1 deg. × 1 deg., in 3.5 years)
1	Latitude: 33 – 46 N Longitude: 114 – 127 E	China: Zhangjiakou, Anshan, Harbin, and Tianjin	3.8 ppm
2	Latitude: 20 – 23 N Longitude: 84 – 89 E	India: Kolkata (Calcutta)	2.0 ppm
3	Latitude: 40 – 41 N Longitude: 67 – 73 E	Eastern part of Uzbekistan, Southern edge of Kazakhstan, Eastern area of Kyrgyzstan, Northern edge of Tajikistan	2.6 ppm
4	Latitude: 30 – 32 N Longitude: 37 – 38 E	Northwestern part of Saudi Arabia, Jordan	1.8 ppm
5	Latitude: 38 – 41 N Longitude: 79 – 83 W	The United States: Pittsburgh	2.1 ppm
6	Latitude: 33 – 35 N Longitude: 114 – 119 W	The United States: Los Angeles	4.5 ppm
7	Latitude: 17 – 19 N Longitude: 99 – 102 W	Mexico: Acapulco	2.4 ppm

Regions with higher CO<sub>2</sub> concentrations from anthropogenic activities are shown in the bottom of Figure 1 and Figure 2 and summarized in Table 1. The regions in Table 1 can be identified as those with dense populations or industrial zones with fossil fuel power plants and developments of oil and gas fields.

Figure 3 shows the relationships between anthropogenic CO<sub>2</sub> concentrations derived from the emission inventory and the observational data acquired by “*IBUKI*” in four regions (Japan, East Asia, North America, and the globe), as shown in the bottom of Figure 1. Key aspects relating to Figure 3 are as follows:

1. Anthropogenic CO<sub>2</sub> concentrations derived from the emission inventory and the observational data acquired by “*IBUKI*” show high correlations in “globe” and “North America”; and the differences in concentration measurements fall within the range of observational error for “*IBUKI*”.
2. Good correlations are also found in the concentrations for “East Asia”; however differences exceed the range of observational error for “*IBUKI*” for some measurements.
3. While there is a correlation between the concentrations for “Japan”, estimation errors for anthropogenic CO<sub>2</sub> concentrations from “*IBUKI*” are significant due to a paucity of observational data.

These results suggest that “*IBUKI*” has the potential to detect enhanced CO<sub>2</sub> concentrations resulting from fossil fuel consumption in mega-cities.

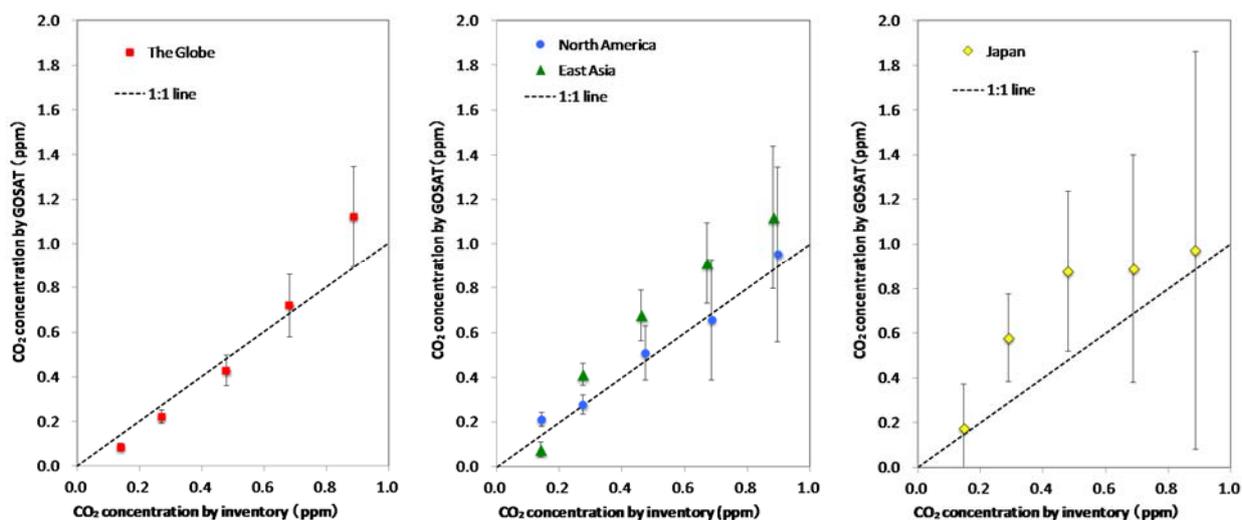


Figure 3 Relationships for anthropogenic CO<sub>2</sub> concentrations derived from emission inventory and “*IBUKI*” for the globe (left), North America and East Asia (center), and Japan (right). Anthropogenic CO<sub>2</sub> concentrations derived from “*IBUKI*” were classified for each 0.2 ppm of concentrations from inventory; average and standard deviation was then calculated in each class. This study excluded data with concentrations from inventory greater than 1 ppm.

### 3. Further steps

The present estimates demonstrated the potential utility of observations by “*IBUKI*” and future satellites to monitor anthropogenic CO<sub>2</sub> emissions. The methodology to improve both the frequency and net volume of observational data by satellites will be further investigated towards an enhancement of the accuracy of estimates of anthropogenic CO<sub>2</sub> concentrations. Additionally, further studies and evaluations, for example, ground-based observation in the surroundings of large emission sources, will be implemented to refine estimates of anthropogenic emission rates from CO<sub>2</sub> concentration measurements acquired by satellites.

#### Notes

1. Column-averaged concentration of CO<sub>2</sub>

The mixing ratio of CO<sub>2</sub> molecules relative to that of dry air, from the earth's surface to the upper extremities of the atmosphere.

2. Anthropogenic CO<sub>2</sub> concentrations estimated from inventory

Inventories of CO<sub>2</sub> emissions from fossil fuel consumption and forest fires, a biospheric model, and an atmospheric tracer transport model were used in this study to estimate anthropogenic CO<sub>2</sub> concentrations by inventory.

3. Inventory of CO<sub>2</sub> emissions by fossil fuel consumption

ODIAC (Open-sources Data Inventory for Anthropogenic CO<sub>2</sub>) was used in this study as inventory for CO<sub>2</sub> emissions by fossil fuel consumption. Oda and Maksyutov, *Atmos. Chem. Phys.*, 11, 543-556, 2011.

4. Database of fossil fuel power plants

CARMA (Carbon Monitoring for Actions) is used in ODIAC as the database for fossil fuel power plants. <http://www.carma.org/plant>

5. Inventory of CO<sub>2</sub> emissions by forest fires

GFAS (Global Fire Assimilation System) was used in this study as inventory for CO<sub>2</sub> emissions by forest fires. Kaiser et al., *Biogeosciences*, 9, 527-554, 2011.