Joint Submission to the first Global Stocktake: The JAXA/GOSAT GHG product for tracking city-level emission changes

The Japan Aerospace Exploration Agency (JAXA) and the Institute for the Global Environmental Strategies (IGES) are pleased to submit an input to the Global Stocktake of the Paris Agreement in response to the mandate of Decision 19/CMA.1, paragraph 19, 36 and 37. Our previous joint submission responded to a mitigation guiding question 3 by presenting the decadal monitoring of global GHG concentration trends using the Greenhouse gases Observing SATellite (GOSAT)[1]. This submission responds to mitigation guiding question 1[2] by giving GHG emissions estimates for world megacities using GOSAT data.

Summary

- Cities are major sources of GHG emissions, consuming about 75% of the world's energy and producing 70% of global carbon emissions[3]. Monitoring trends of emissions can help cities identify emission sources to more effectively achieve their pledges.
- JAXA developed the *space-based surface GHG Emission Indicator (GEI)* for tracking emission changes at key subnational policy-relevant levels, such as cities. JAXA's GEI is based on the difference between the upper and lower-tropospheric CO_2 and CH_4 concentrations.
- Of the six-year CO_2 emission trends for the Greater Tokyo Area (Figure 1), the *GEI* indicates a large emission reduction in 2020, attributed to the significantly reduced economic activities during the COVID-19 pandemic.
- *GEI* is available from the JAXA/GOSAT GHG product. JAXA also plans to release a CH_4 version of *GEI* to contribute toward local climate mitigation pledges.

[1] GOSAT is a joint project of the Japan Aerospace Exploration Agency (JAXA), the Ministry of the Environment (MOE), and the National Institute for Environmental Studies (NIES).
[2] What are the past and present trends of greenhouse gas (GHG) emissions by sources and removals by sinks -and their underlying drivers- and mitigation efforts undertaken by Parties -and their impacts on emissions and removals, including based on the information referred to in Article 13, paragraph 7(a), and Article 4, paragraphs 7, 15 and 19, of the Paris Agreement (para 36(a))?
[3] United Nations Human Settlements Programme (UN HABITAT) (2020). World Cities Report 2020. https://unhabitat.org/sites/default/files/2020/10/wcr_2020_report.pdf

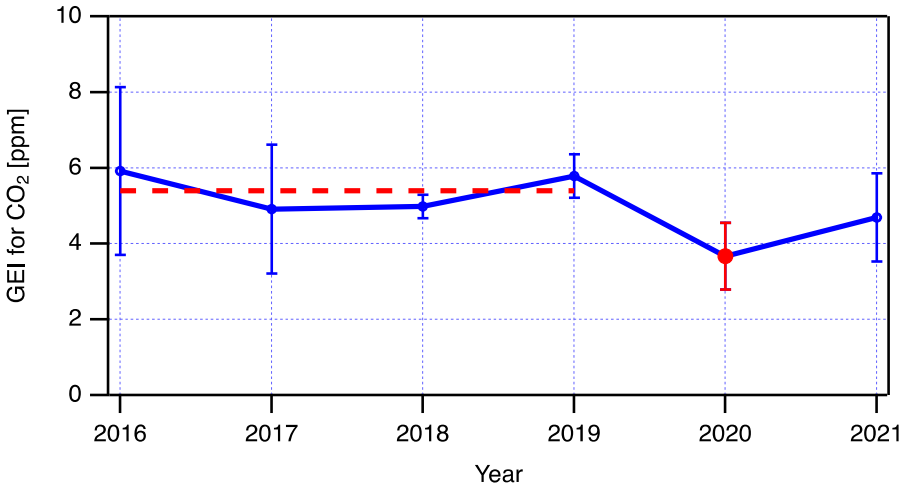

Figure 1. The six-year CO_2 emission trends in the Greater Tokyo area derived from *GEI*. *GEI* is calculated with JAXA/GOSAT GHG product from January to April to assess the local concentration enhancement due to local emissions. The average of *GEI* between 2016 and 2019 is plotted with a dotted red line.

1. Methodology

1.1 Overview of GHG observations by Japan's GOSAT satellite

Japan's Greenhouse gases Observing SATellite (GOSAT) was launched as the first GHG-dedicated satellite on the 23rd of January 2009. Since then, GOSAT has monitored changes in atmospheric carbon dioxide (CO_2) and methane (CH_4) to advance our understanding of the global carbon cycle and support climate monitoring.

The GOSAT observation concept is illustrated in the right image of Fig. 3. GOSAT observations are based on remote sensing and measure the solar light reflected from the Earth's surface for collecting atmospheric CO_2 and CH_4 data. GOSAT carries a Thermal and Near Infrared Sensor for Carbon Observation Fourier-Transform Spectrometer (TANSO-FTS). The spectrometer detects gas absorption spectra of solar radiation in the ShortWave-InfraRed (SWIR) region reflected from the Earth's surface and the Thermal Infrared Radiation (TIR) emitted from the ground and the atmosphere. TANSO-FTS simultaneously measures the spectra at the oxygen A band (0.76 μm), weak and strong CO_2 bands (1.6 and 2.0 μm), weak CH_4 bands (1.6 μm) with orthogonal polarizations, and a wide TIR band (5.5–14.3 μm) with 0.2 cm^{-1} spectral sampling intervals. GOSAT has been collecting global CO_2 and CH_4 data continuously every three days with a circular observation footprint of 10.5 km diameter from an altitude of 666 km.

GOSAT pioneered the two-axis agile pointing mechanism for implementing special target mode observations for megacities and large power plants. This mechanism has been adopted by other state-

of-the-art satellites, such as NASA's OCO-3 and GOSAT-2. The pointing system allows us to implement multiple observation patterns tailored for target emissions and removals, such as nominal grid observations over land, glint observations over oceans, and target observations over megacities and large point sources. The technical details of the GOSAT satellite are described in Kuze et al., 2009, 2016.

1.2 JAXA/GOSAT GHG products

Several research teams have utilized GOSAT data to retrieve the column concentration of both CO_2 and CH_4. While there are several retrieval methods, most focus on using the reflected sunlight spectra in the SWIR region for retrieving the total column information. In contrast to conventional methods, JAXA developed a retrieval algorithm to derive vertical concentration information by using reflected sunlight with two orthogonal polarizations and thermal emissions observed by GOSAT. The product allows us to use concentration information for the lower and upper troposphere to assess surface emissions better. The two-layer vertical concentration information, especially the one near the surface, will enhance our ability to examine surface emissions and removals and advance our understanding of the carbon cycle.

Figure 2 shows a schematic diagram of the satellite GHG observation concept and the difference between conventional total-column GHG retrieval data and the JAXA/GOSAT GHG product (with two-layer vertical information). Due to CO_2 emissions and removals at the surface, the lower troposphere concentration should reflect surface emissions more directly than the total column-averaged concentration. The JAXA/GOSAT GHG product includes both total and two-layer vertical concentration to assess anthropogenic emissions better. A detailed technical overview is described in Kikuchi et al., 2017.

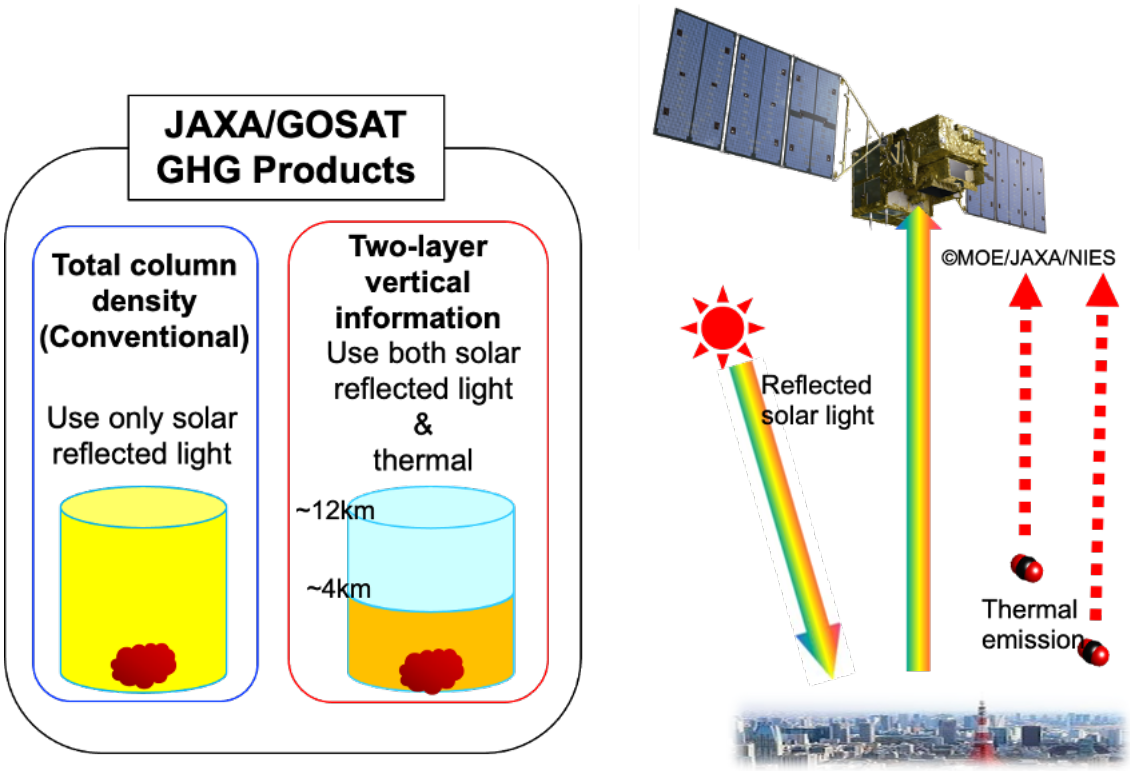

Figure 2. A schematic diagram of the JAXA/GOSAT GHG product

1.3 Space-based surface GHG Emission Indicator (GEI)

Estimations of GHG emissions from local sources often start with calculating CO_2 and CH_4 concentration enhancements solely due to the emission sources of interest. One of the biggest challenges in calculating these enhancements is to define a background that can be used for a reference regardless of the presence of many different CO_2 sources. JAXA developed the *space-based surface GHG Emission Indicator (GEI)* to utilize the two-layer vertical information in the JAXA/GOSAT GHG product. *GEI* defines CO_2 and CH_4 concentration enhancement as the difference between the upper and lower-tropospheric CO_2 and CH_4 concentrations. The upper-tropospheric concentrations are used as the background in the *GEI* calculation. As illustrated in Fig. 2, the lower tropospheric CO_2 concentration should capture changes in the surface emissions better than the total column average concentration. Then, we assumed that the upper troposphere is less affected by the local emission. The technical details are described in Kuze et al., 2021.

2. Results

In addition to the global grid observation, GOSAT has implemented target observations at specific locations where climate mitigation impacts are expected, such as cities. Figure 3 presents target observations over the Greater Tokyo Area on March 17, 2015. As shown in Fig. 3, the JAXA/GOSAT

GHG product provides both the total column concentration of GHG and the two-layer vertical information (lower troposphere and upper troposphere concentration). The lower-tropospheric concentration data showed a higher CO_2 concentration than the upper-tropospheric concentration in the winter. While CO_2 contributions from the local terrestrial biosphere could be nonnegligible, the more elevated CO_2 is attributed primarily to the local emissions from human activities in the Greater Tokyo Area. This result demonstrated that the lower-tropospheric concentration data are more susceptible to local CO_2 emission than the conventional total column concentration. Target observations have been implemented over global megacities to collect more GHG data to track the emission changes. Our results suggested a potential emission tracking skill of the JAXA/GOSAT GHG product.

Our *GEI* analysis also suggests that *GEI* could inform us of timely emission changes due to human activity changes in megacities. Figure 1 compares the *GEI*-based CO_2 emission estimation changes over the Greater Tokyo Area from 2016 through 2021. *GEI* indicated significant emission reductions in 2020 compared to the previous years. The timing of the significant emission reductions in 2020 is consistent with that reported in the literature[4]. The emission reduction is attributed to the reduced economic activities during the COVID-19 pandemic.

These results suggest that the JAXA/GOSAT GHG product has a unique potential to track emissions changes over megacities, accelerating our understanding of the carbon cycle and climate actions toward the Global Stocktake (GST).

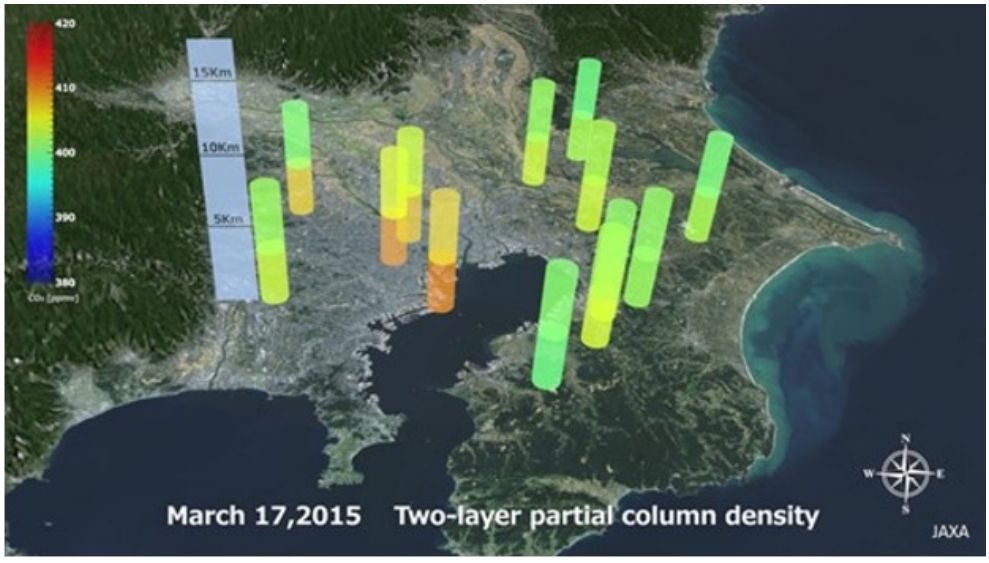

Figure 3. An example of target observations over the Greater Tokyo Area and retrieved two-layer CO_2 concentration data.

[4]e. g., https://www.nies.go.jp/whatsnew/20211210/20211210-e.html

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4. Reference

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