Joint Submission to the first Global Stocktake: The decadal global atmospheric greenhouse gas concentration trends observed by Japan's Greenhouse gases Observing SATellite (GOSAT)

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. This submission provides our input for mitigation guiding question 3[1]:

Summary

- A decadal global JAXA/GOSAT GHG product shows continued increases in global CO_2 and CH_4, which increased by 29 ppm and 97 ppb from June 2009 to June 2021, respectively. The product also presents the seasonal cycles of concentrations that are primarily attributable to natural GHG removals and the resulting carbon budget.
- The Greenhouse gas Observing SATellite (GOSAT)[2] is the world's first GHG-dedicated space-based observatory launched in 2009 by Japan. GOSAT simultaneously monitors global changes in CO_2 and CH_4 atmospheric concentrations.
- GOSAT observations have collected CO_2 and CH_4 data over areas where ground-based observations are unavailable or sparse. GOSAT can monitor CO_2 and CH_4 at 100 times the number of locations than ground-based observation, filling in the observational gaps and collecting data on areas where climate mitigation impacts are expected, such as megacities.
- The JAXA/GOSAT GHG product is publicly available to assess CO_2 and CH_4 concentration changes. The product directly contributes to elucidating the global and local carbon cycle and monitoring the nation's climate mitigation efforts toward the Paris Climate goal.

1 What are the trends of the concentration of GHGs in the atmosphere and global average temperature and what global emission pathways are consistent with the goals set out in Articles 2 para 1(a) and Article 4.1?

2 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).

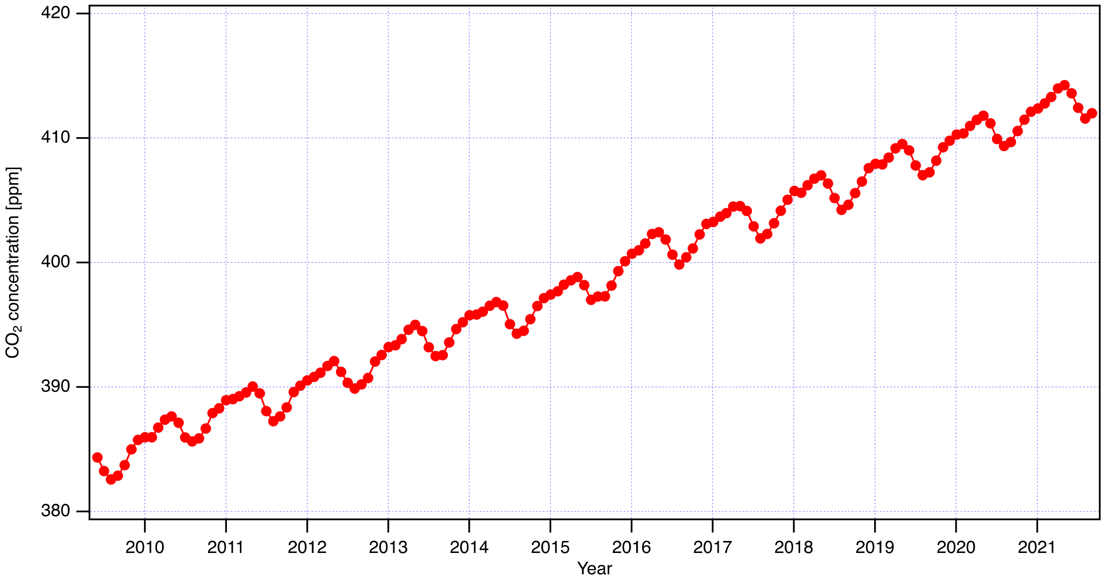

Figure 1. Monthly average CO_2 changes (red).

The JAXA/GOSAT CO_2 data between 70° N and 50° S are averaged for each month.

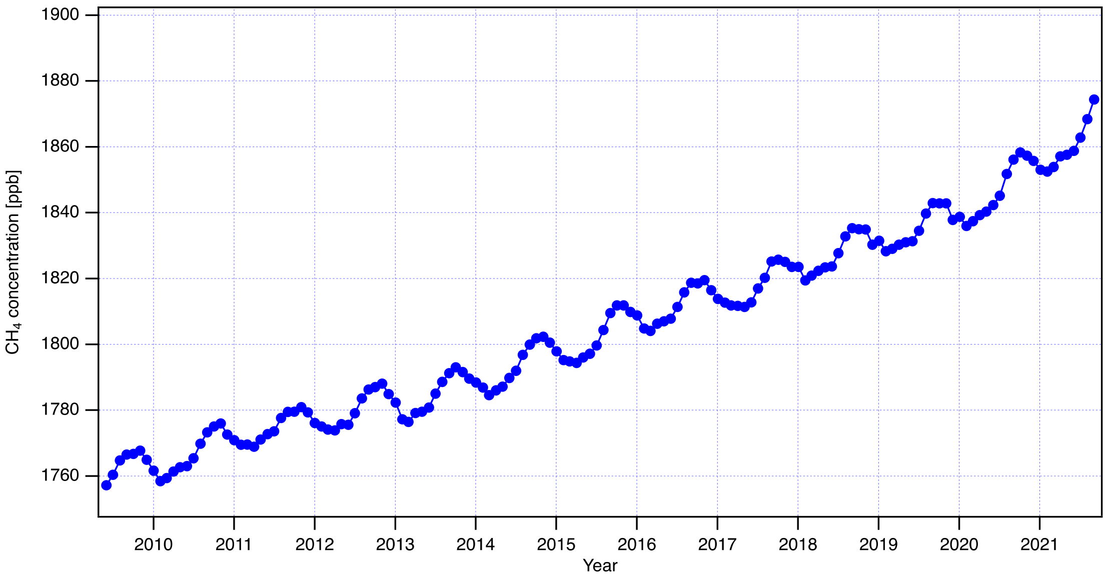

Figure 2. Monthly average CH_4 changes (blue).

The JAXA/GOSAT CH_4 data between 70° N and 50° S are averaged for each month.

Table 1. A summary of the JAXA GOSAT GHG product

Items	Description
Monitored GHGs	CO_2, CH_4
Variables	Total, lower, and upper troposphere column concentrations
Indicator for GHG emissions and removals	Solar induced fluorescence (SIF) for emissions/removals (natural)
Target spatial scale (s) of emissions and removals	Global, regional, national, and subnational (cities)
Period	June 2009-Pressent
Frequency	Monthly
Uncertainty	2 ppm for total column CO_2, 17 ppb for total column CH_4
Data access	https://www.eorc.jaxa.jp/GOSAT/index.html

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 reflected from the Earth's surface in the Short-Wave InfraRed (SWIR) region and the Thermal Infrared Radiation (TIR) emitted by the ground and the atmosphere. TANSO-FTS can simultaneously measure 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 accumulated 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 of megacities and large power plants. This mechanism has been adopted by other state-of-the-art satellites, such as OCO-3 and GOSAT-2. The pointing system allows us to implement multiple observation patterns tailored for target emissions and removals, such as gird 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 3 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.

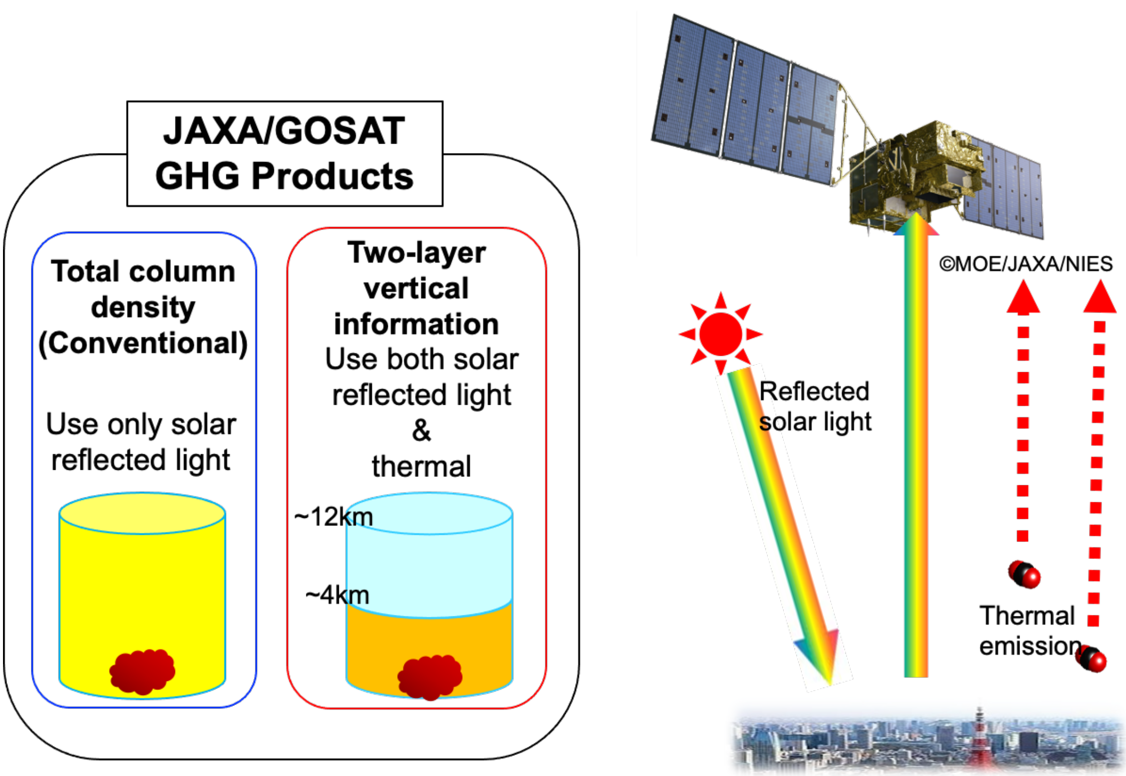

Figure 3. A schematic diagram of the JAXA/GOSAT GHG product

2. Results

The monthly averaged CO_2 and CH_4 changes and trends are presented in Figs. 1 and Fig.2, respectively. JAXA/GOSAT GHG data in the region between 70° N and 50° S were averaged to obtain monthly average CO_2 and CH_4 values. The trends in CO_2 and CH_4 concentrations were calculated as the polynomial part of Eq. 1.

$$f(t) = a_0 + a_1 t + a_2 t^2 + \sum_{n=1}^{2} C_n[sin(2n\pi t + \varphi_n)]$$

Eq.1.

The trends of CO_2 and CH_4 clearly show the increase of atmospheric CO_2 and CH_4 in the last decade.

The latitudinal monthly average CO_2 changes are plotted in Fig. 4 with the fit lines based on Eq. 1. As shown in Fig. 4, larger seasonal variation and higher concentrations are observed in the northern hemisphere because of the large terrestrial sinks in this region and the emissions from most industrialized countries.

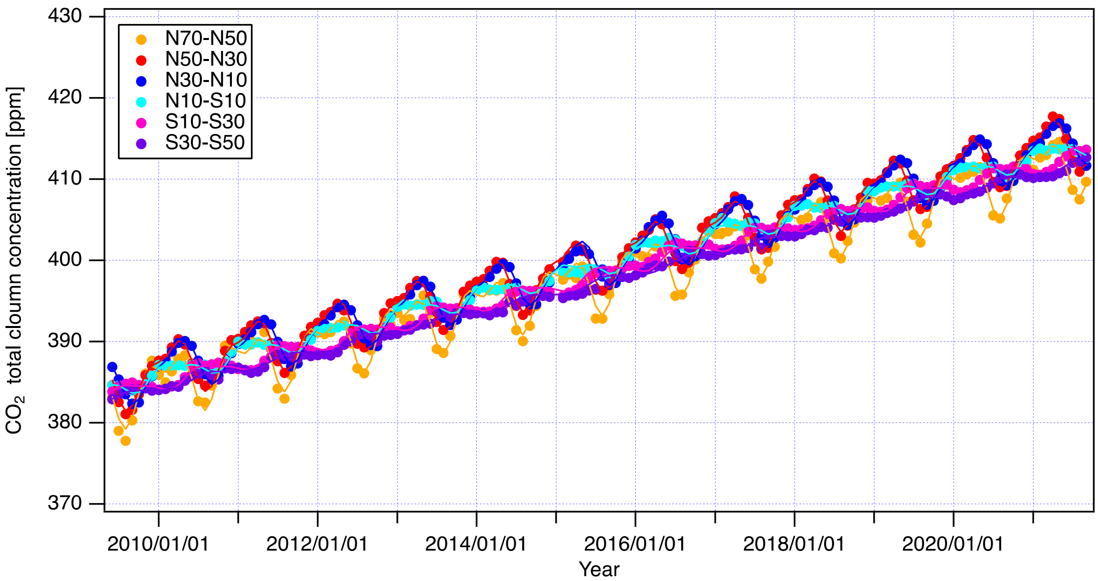

Figure 4. Latitudinal monthly average CO_2 changes with the function fit lines. The JAXA/GOSAT CO_2 data are averaged for each 20° latitudinal bin. Lines are color-coded by latitude.

The latitudinal monthly averaged CH_4 changes are plotted in Fig. 5. Like the CO_2 feature, the larger seasonal amplitudes and higher concentrations were observed in the northern hemisphere. For CO_2, the seasonal variation in the southern hemisphere is milder than in the northern hemisphere. In contrast, the seasonal variation of CH_4 in the southern hemisphere is also clearly observed with a phase different from that of the northern hemisphere.

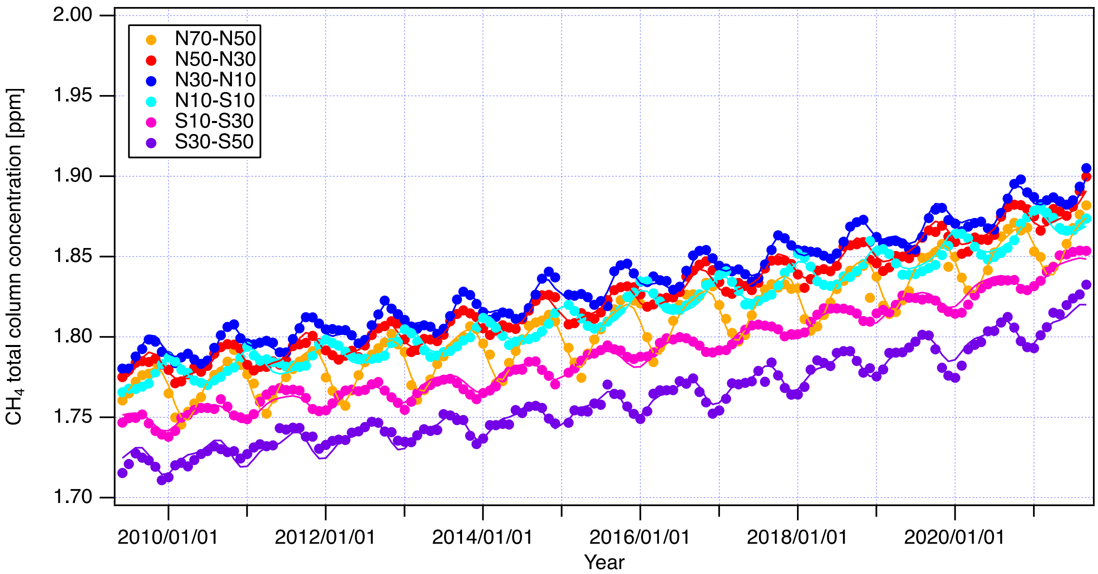

Figure 5. Latitudinal monthly average CH_4 changes with the function fit lines.
The JAXA/GOSAT CH_4 data are averaged for each 20° latitudinal bin. Lines are color-coded by latitude.

As shown in Figs. 1 and 2, JAXA/GOSAT GHG products present the global CO_2 and CH_4 concentration changes. Features such as seasonal trends are similar to ground-based observations. Figures 6 and 7 show the locations of ground-based in-situ observation stations and GOSAT observation points in June 2021, respectively. Comparing the observation locations between the global ground-based network and the satellite-based (GOSAT) observation, the GOSAT observations collect CO_2 and CH_4 data over the areas where ground-based observations have not been available or are sparce. GOSAT can provide more than 100 times the number of CO_2 and CH_4 observation points to fill such observation gap areas.

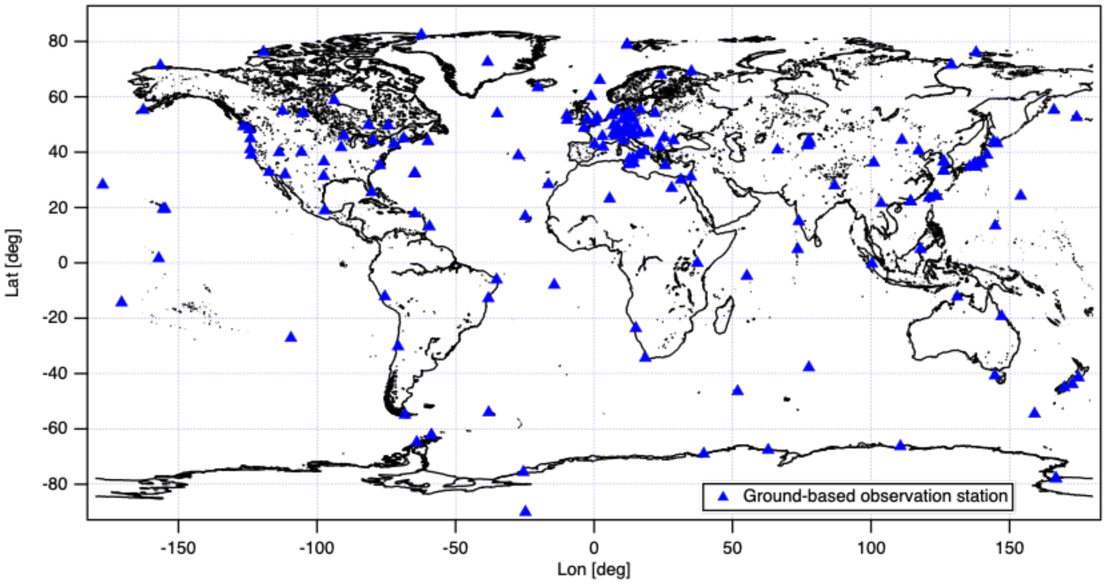

Figure 6. The world distribution of ground-based observation stations.

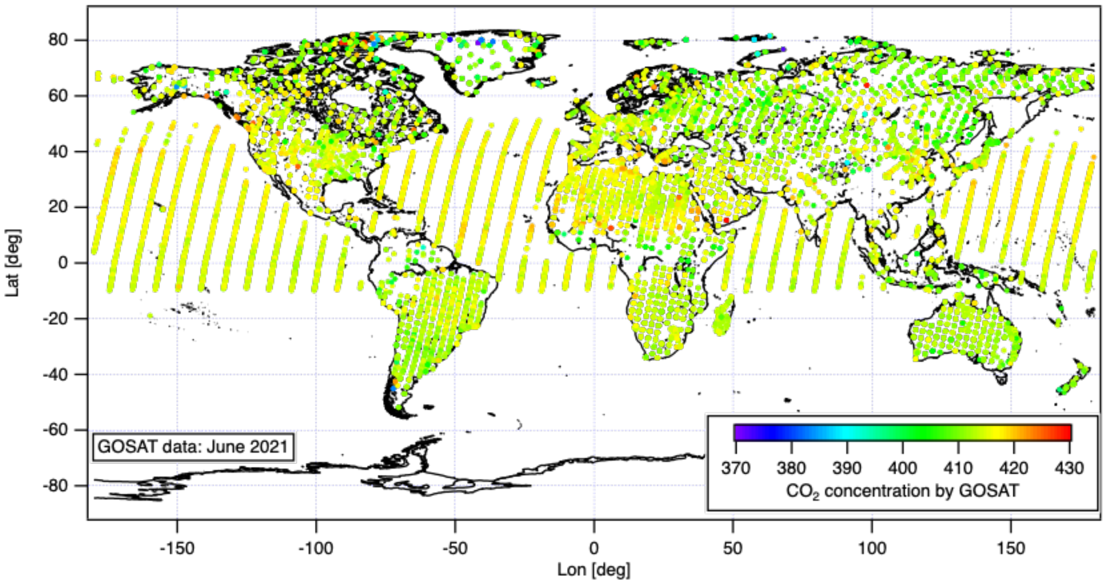

Figure 7. the GOSAT observation track in June 2021.

3. Contact Persons

Hiroshi Suto, Japan Aerospace Exploration Agency, suto.hiroshi@jaxa.jp

Akibi Tsukui, Institute for Global Environmental Strategies, tsukui@iges.or.jp

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