# Validations of the latest GOSAT series Level2 products

Yukitomo Tsutsumi<sup>1</sup>, Isamu Morino<sup>1</sup>, Tomoaki Tanabe<sup>1</sup>, Akihiro Hori<sup>1</sup>, Kenji Yamaguchi<sup>1</sup>, Matthias M. Frey<sup>2</sup>, Hirofumi Ohyama<sup>1</sup>, Yu Someya<sup>1</sup>, Yukio Yoshida<sup>1</sup>, Tsuneo Matsunaga<sup>1</sup>, Akihide Kamei<sup>1</sup>, Makoto Saito<sup>1</sup>, Hibiki M. Noda<sup>1</sup>, and TCCON partners.

> 1: National Institute for Environmental Studies (NIES), Tsukuba, Japan 2: Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany

#### 1. Introduction

The Ministry of the Environment (MOE), the Japan Aerospace Exploration Agency (JAXA), and the National Institute for Environmental Studies (NIES) are conducting the Greenhouse gases Observing SATellite ("Ibuki" (GOSAT) and "Ibuki-2" (GOSAT-2)) series project to measure column-averaged dry-air mole fractions of the major greenhouse gases (GHG), such as carbon dioxide and methane, from space. For use of GOSAT series SWIR Level2 products in scientific researches and GHG reduction policies, it is essential to make continuous validations to ensure the accuracy of GOSAT series SWIR Level2 products on GHG concentrations.

We conducted the validations of the latest versions of GOSAT FTS SWIR Level2 product (Ver. 03.10) and GOSAT-2 FTS SWIR Level2 Full Physics product and PROXY product (Ver.02.20) by compared with Total Carbon Column Observing Network (TCCON) data. Here, we abbreviate GOSAT FTS SWIR Level2 product to "GOSAT product", and GOSAT-2 FTS-2 SWIR Level2 Full Physics product to "GOSAT-2 Full Physics product" and GOSAT-2 FTS-2 SWIR Level2 Chlorophyll Fluorescence and Proxy-method product to "GOSAT-2 PROXY product". AXgas means the difference (bias) between GOSAT series products and TCCON data.

## 2. Conditions and collocations of GOSAT series products for validations using TCCON data

#### 2.1 GOSAT products

The GOSAT products of Ver. 03.10 with the period of April 23, 2009 – December 31, 2022 is used in the validation. The area definitions are "Land" (100% of land fraction) and "Ocean" (0% of land fraction). The gains used are Gain H and Gain M over Land and Gain H over Ocean. The TCCON data are obtained from the TCCON data archive (http://tccondata.org/). They are as of November 2024 and processed by GGG2020. The TCCON data are averaged over within ±30 min of GOSAT-2 overpass time for the validation.

The conditions and collocations for the comparison of GOSAT and TCCON data are as follows:

- Comparison area: ±0.1°, ±1°, ±2°, ±5° latitude / longitude box centered at the TCCON sites.
- Column averaging kernels and prior profiles are not considered for the validation analysis.
- The GOSAT products with a difference between the footprint altitude and the altitude of the TCCON site greater than 500 m are excluded from the comparison.

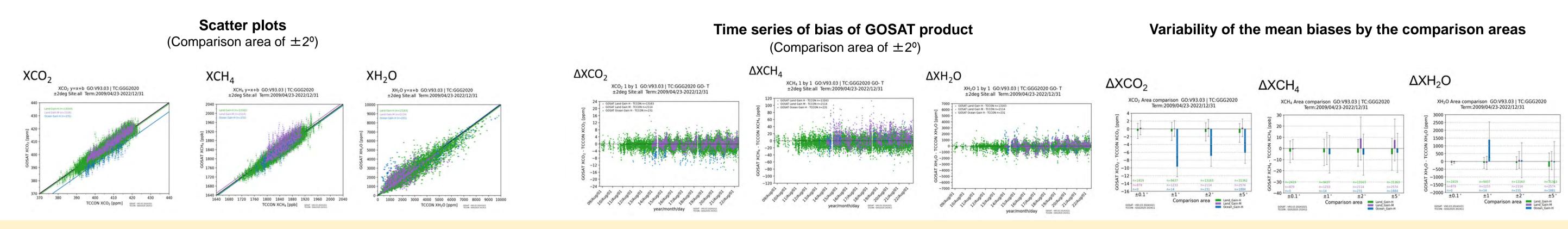
In the GOSAT products, the major change from the previous products (Ver. 03.00) is updating of the variance-covariance matrix.

#### 2.2 GOSAT-2 Full Physics products and GOSAT-2 PROXY products

The GOSAT-2 Full Physics products and GOSAT-2 PROXY products of versions of 02.20 with the period of March 1, 2019 - February 29, 2024 are used in the validations. The area definitions are "Land" (≥ 10% of land fraction) and "Ocean" (< 10% of land fraction). Only data with the quality flag "good" are used. No distinction is made by gain in these analyses. The TCCON data are obtained from the TCCON data archive (http://tccondata.org/). They are as of February 2025 and processed by GGG2020. Other conditions are same as the GOSAT products (except the PROXY products which do not take into account column averaging kernels and prior profiles).

In the GOSAT-2 Full Physics products and GOSAT-2 PROXY products, major changes from the previous version (Ver.02.10) are as follows: The meteorological reanalysis data are changed from JRA-55 to JRA-3Q, and the variancecovariance matrices are updated to those based on JRA-3Q. The prior CO<sub>2</sub> and CH<sub>4</sub> field and their corresponding variance-covariance matrices are updated.

### 3. Results of validation of GOSAT products of Ver. 03.10 (April 23, 2009 ~ December 31, 2022)



#### Summary of validation of GOSAT products of Ver.03.10

The GOSAT products of Ver. 03.10 for XCO<sub>2</sub>, XCH<sub>4</sub> and XH<sub>2</sub>O are compared with the TCCON data for validation. In the comparison area of  $\pm 2^{\circ}$  obtained, the results of GOSAT products validation are summarized as follows.

• The mean biases and the standard deviations of XCO<sub>2</sub>, XCH<sub>4</sub>, and XH<sub>2</sub>O are showed in the Table 1.

Table 1. Mean biases and standard deviations of GOSAT product (Ver.03.10) against ground-based FTS observations ( $\pm 2^{\circ}$ )

		Gain	XCO <sub>2</sub>			XCH <sub>4</sub>			H <sub>2</sub> O		
			Number	[ppm]	[%]	Number	[ppb]	[%]	Number	[ppm]	[%]
_	Land -	Gain H	13163	-0.78±2.32	- 0.19 ±0.57	13163	-3.93±12.08	−0.21±0.65	13163	-102.8± 409.0	−2.5± 19.4
		Gain M	2114	0.25±2.18	0.06±0.53	2114	8.93±19.26	0.48±1.04	2114	90.1± 544.4	11.6± 34.3
	Ocean	Gain H	231	-6.91±2.69	- 1.71±0.66	231	-5.61±18.40	−0.31±1.01	231	71.6±1124.7	48.3 ±115.9

No significant trends are recognized for biases of the gas species during the period of validation.

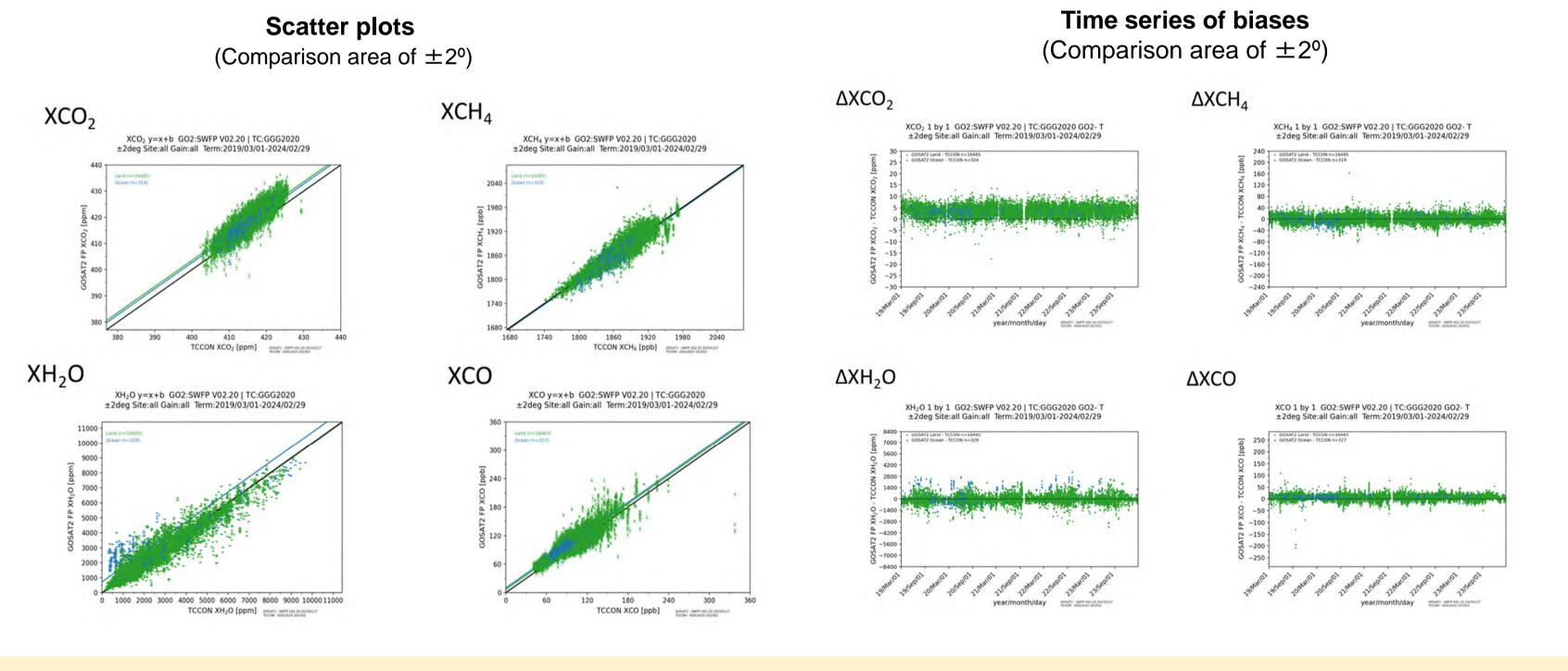
The validation of GOSAT products in the other comparison areas are summarized as follows.

- For XCO<sub>2</sub>, the biases over Land and Ocean are negative in all areas by Gain H, except area of  $\pm 0.1^{\circ}$  over Ocean where no data are available. In contrast, the mean biases by Gain M over Land are positive in all areas. The absolute mean biases over Ocean are particularly larger than those over Land, and the absolute values are decreasing with broadening the comparison area.
- For XCH<sub>4</sub>, the mean biases over Land and Ocean are negative in all areas by Gain H in all areas, except the area of ±0.1° over Ocean where no data are available. The absolute mean values of bias by Gain M over land are less than 1 ppb in the areas of  $\pm 0.1^{\circ}$  and  $\pm 1^{\circ}$ , but  $7\sim9$  ppb in the areas of  $\pm2^{\circ}$  and  $\pm5^{\circ}$ .
- For XH<sub>2</sub>O, the mean relative bias is outstanding in the area of ±1° over Ocean, but this is due to the small amount of data over Ocean (14 data) and an Izana's very large relative bias. As the comparison area is broadened (to  $\pm 2^{\circ}$  and  $\pm 5^{\circ}$ ), the amount of data over Ocean increases significantly, resulting in much smaller biases over Ocean.

The absolute differences of the mean-bias of XCO<sub>2</sub> and XCH<sub>4</sub> of this products from those of the previous GOSAT products of Ver.03.00

including other gains and areas are very small and within 0.16% of the biases. There is no version-dependent difference in the trends.

## 4. Results of validation of GOSAT-2 Level2 Full Physics products of Ver. 02.20 (March 1, 2019 ~ February 29, 2024)



# XCO<sub>2</sub> Area comparison GO2:SWFP V02.20 | TC:GGG2020 XCH<sub>4</sub> Area comparison GO2:SWFP V02.20 | TC:GGG2020 Gain:all Term:2019/03/01-2024/02/29 Gain:all Term:2019/03/01-2024/02/29 XH<sub>2</sub>O Area comparison GO2:SWFP V02.20 | TC:GGG2020 XCO Area comparison GO2:SWFP V02.20 | TC:GGG2020 Gain:all Term:2019/03/01-2024/02/29

Variability of the mean biases by the comparison areas

# Summary of validation of GOSAT-2 Full Physics products of Ver.02.20

The GOSAT-2 Full Physics products of Ver. 02.20 for XCO<sub>2</sub>, XCH<sub>4</sub>, XH<sub>2</sub>O, and XCO are compared with the TCCON data for validation. In the comparison area of  $\pm 2^{\circ}$ , the results of GOSAT-2 Full Physics products validation are summarized as follows.

- Mean biases and standard deviations of GOSAT-2 Full Physics products (Ver.02.20) against ground-based FTS observations  $(\pm 2^{\circ})$  are showed in Table 2.
- No specific trends of bias are found for all species observed during the observation period.

Table 2. Mean biases and standard deviations of GOSAT-2 Full Physics product (Ver.02.20) against ground-based FTS observations ( $\pm$ 2°)

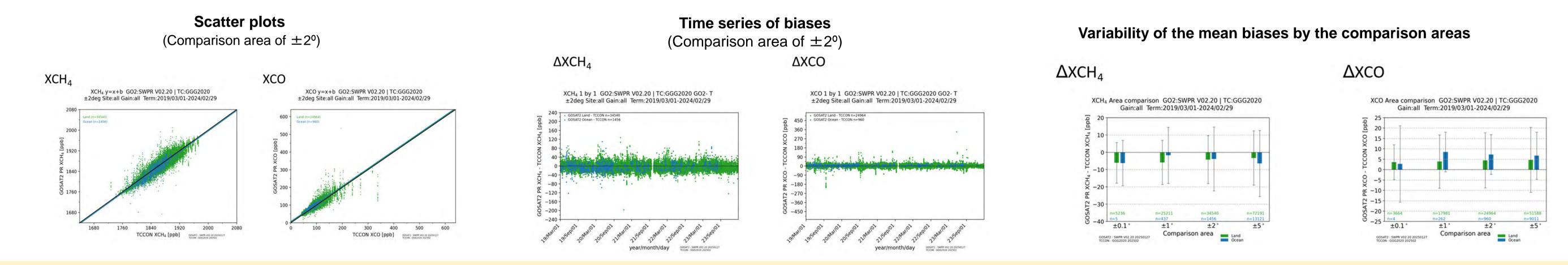
		$XCO_2$		XCH₄				
	Number	[ppm]	[%]	Number	[ppb]	[%]		
Land	16485	3.54±2.17	0.85±0.52	16485	0.53±12.71	0.03±0.67		
Ocean	324	2.69±2.22	0.65±0.54	319	-2.39±16.89	−0.13±0.91		
		$XH_2O$		XCO				
	Number	[ppm]	[%]	Number	[ppb]	[%]		
Land	16485	-38.3± 409.6	1.0± 21.6	16483	6.81±11.15	7.93±10.85		
Occor	220	704 0 4440 0	440 0 407 0	207	40.04. 7.04	40.00.050		

Area comparison of the mean biases are summarized as follows. Note that there is no data of the area of  $\pm 0.1^{\circ}$  over Ocean for all atmospheric species. • For XCO<sub>2</sub>, all the mean biases are positive and all the mean biases over Land are larger than those over Ocean. All the standard

- deviations are smaller than the mean biases.
- For XCH<sub>4</sub>, the signs of mean biases depends on the comparison areas, but all the standard deviations are larger than the biases. The absolute mean biases over Ocean are increasing with broadening the area.
- For XH<sub>2</sub>O, all the mean biases over Land are negative and the absolute biases are much smaller than those over Ocean. All the mean biases over Ocean are positive and those are decreasing with broadening the area.
- For XCO, all the mean biases are positive. The mean biases over Ocean are larger than those over Land. All the mean biases over Land are relatively stable, and they are within the range of 6 to 7 ppb. The mean biases over Ocean are decreasing with broadening the area.

The absolute differences of the mean-bias of XCO<sub>2</sub> and XCH<sub>4</sub> of this products from those of the previous products of Ver.02.10 including other gains and areas are very small and within 0.03% of the biases. There is no version-dependent difference in the trends.

# 5. Results of comparison of GOSAT-2 PROXY products of Ver. 02.20 (March 1, 2019 ~ February 29, 2024)



# Summary of validation of GOSAT-2 PROXY products of Ver.02.20

The GOSAT-2 PROXY products of Ver. 02.20 for XCH₄ and XCO are compared with the TCCON data for validation. In the comparison area of  $\pm 2^{\circ}$ , the results of GOSAT-2 PROXY products validation are summarized as follows.

 Mean biases and standard deviations of GOSAT-2 PROXY product (Ver.02.20) against ground-based FTS observations ( $\pm 2^{\circ}$ ) are showed in Table 3.

- For XCH<sub>4</sub>, the absolute mean biases over Land and Ocean are lower than 10 ppb, and the both absolute mean relative biases are very small and less than 1%.
- For, XCO, the absolute mean biases over Land and Ocean are lower than 10 ppb.
- No specific trends of bias are found for all atmospheric compositions observed during the observation period.

Table 3. Mean biases and standard deviations of GOSAT-2 PROXY product (Ver.02.20) against ground-based FTS observations ( $\pm 2^{\circ}$ )

XCH<sub>4</sub> XCO [ppb] [ppb] [%] Number [%] Number -0.22±0.74 24964 4.46±13.26 5.28±11.50 34540 -4.19±13.87 1456 -3.84±18.42 960 7.29± 9.56 9.28±10.99 -0.21±1.00

The results of GOSAT-2 PROXY products validation in other conditions are summarized as follows.

- For XCH<sub>4</sub>, the mean biases over Land are negative and within the range from -7 to -3 ppb in all the comparison areas. Similar to the biases over Land, those over Ocean are all negative and within the range from -7 to -1 ppb. All the standard deviations of both Land and Ocean are larger than the biases.
- For XCO, the mean biases over Land are positive and within the range from 3 to 5 ppb in all the comparison areas. The mean biases over Ocean are also all positive and within the range from 2 to 9 ppb. All the standard deviations of both Land and Ocean are larger than the biases.

The absolute differences of the mean-bias of XCH₄ and XCO of this products from those of the previous products of Ver.02.10 including other gains and areas are very small and within 0.04% for XCH<sub>4</sub> and within 0.93% for XCO of the biases, respectively. There is no versiondependent difference in the trends.