Overview of the Special Report

環境省
Ministry of the Environment

Greenhouse Gas Observation from Space

Long-term Satellite Observations since 2009 and the Future of the GOSAT Series

(December 2023)

Ministry of the Environment, Government of Japan

National Institute for Environmental Studies,

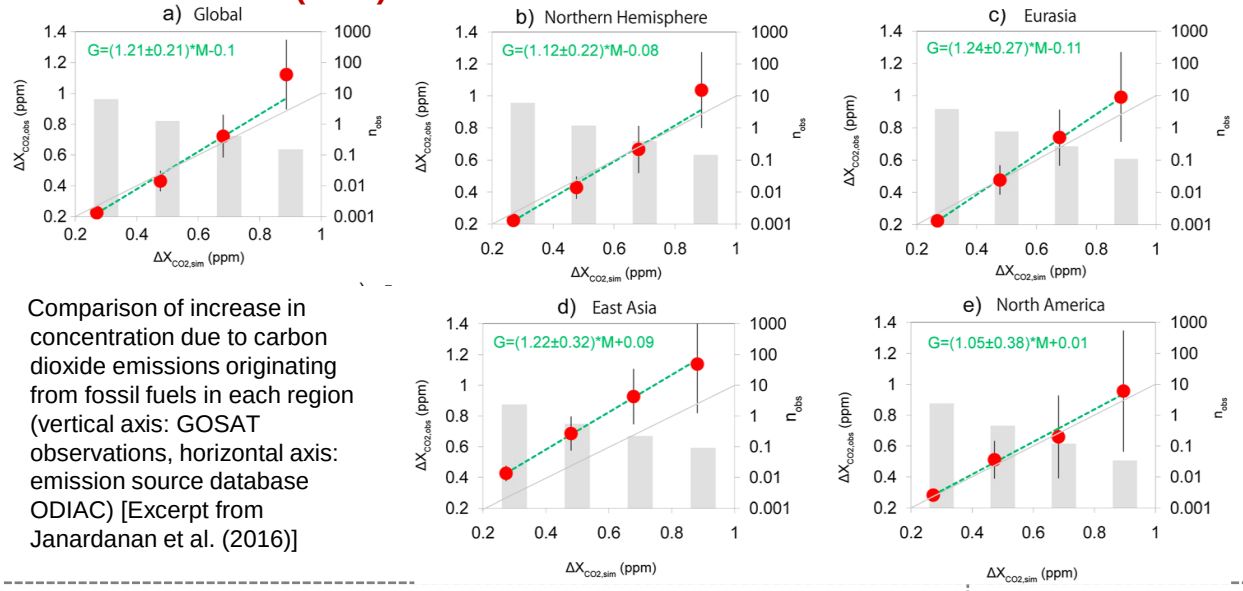
Main achievements of the GOSAT series and future operation (executive summary)

Major Achievements of the GOSAT Series

The GOSAT series has provided data on CO2, methane without compensation **for 15 years since 2009**. Its research are utilized in climate change research and policies globally, including the **IPCC report** (**24 GOSAT-related papers referenced**).

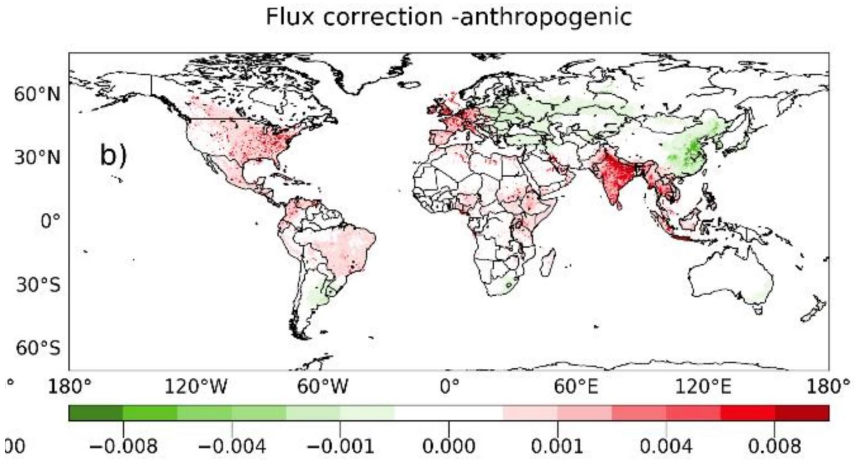
- There are differences between the anthropogenic greenhouse gas emissions volumes estimated from GOSAT series satellite measurements and those estimated from official statistics on fossil fuel usage and reports submitted by each country to the UNFCCC. **These differences have been observed in certain regions such as East Asia**.
- More detailed monitoring and management of emission sources will become increasingly important. The MOE aims to contribute to **transparency in global emission reporting** using the GOSAT-GW satellite to be launched in FY2024.

【 Janardanan et al.(2016) 】



Comparison of increase in concentration due to carbon dioxide emissions originating from fossil fuels in each region (vertical axis: GOSAT observations, horizontal axis: emission source database ODIAC) [Excerpt from Janardanan et al. (2016)]

【 Janardanan et al.(2020)】



Difference between observed values from GOSAT and a priori values for anthropogenic absorption and emission volumes of methane [excerpt from Janardanan et al (2020)]

Efforts to enhance GOSAT monitoring precision

One effort is analysis and calibration utilizing observation data from ground-level monitoring devices, ships, and airplanes. Joint observations with the US (NASA), Europe (ESA), and other space agencies are taking place too.

Joint observations by NASA, ESA, and JAXA in Nevada（from the JAXA website ）

Future issues and initiative policy

Japan plans to launch GOSAT-GW, the third satellite in the GOSAT series, in FY2024.

It is also conducting a review of a successor satellite for the 2030s.

Pioneering efforts are taking place to prevent GOSAT from becoming space debris too.

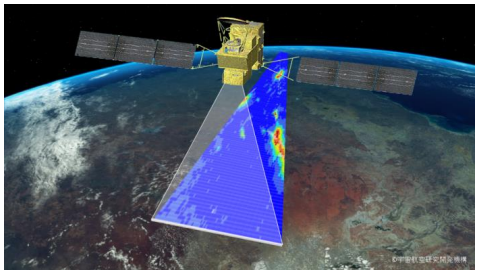


Image of observation by GOSAT-GW TANSO-3 (wide-area observation mode)

Major GOSAT Series Achievements: Global Observation

- GOSAT satellites have been continuously observing **a global GHGs since 2009**.
- **More than 600 papers** related to the GOSAT series have been published, and **24 papers** are referenced in **the IPCC AR6 WG1** report.
- Review of continuity in measurement data from GOSAT and GOSAT-2 finished in September 2023. The GOSAT series **delivers long-term, global GHG data with continuity to the world without compensation.**

Significance of satellite-based long-term, global observation

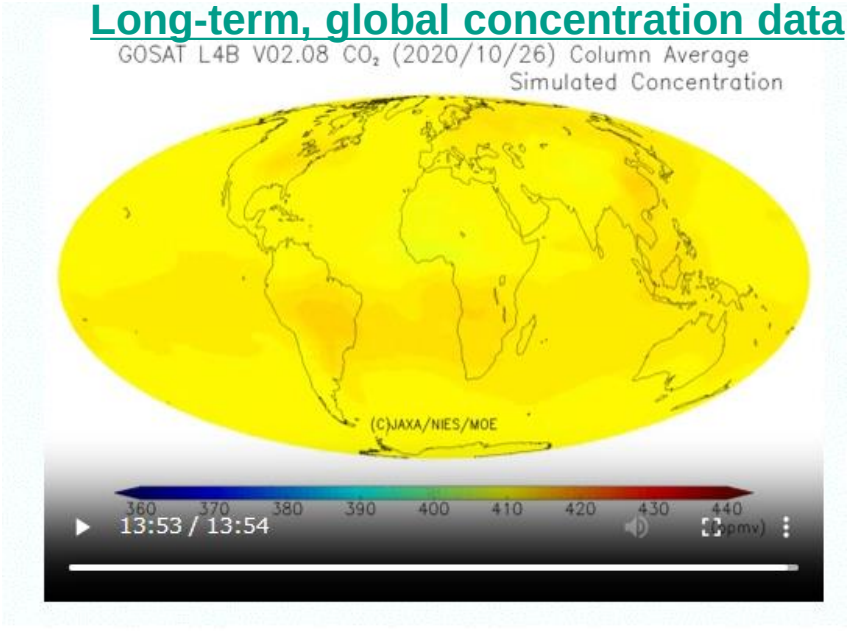
・Atmosphere concentration will be detectable in a **relatively short period (5-10 years)**

・**Ground based measurement**

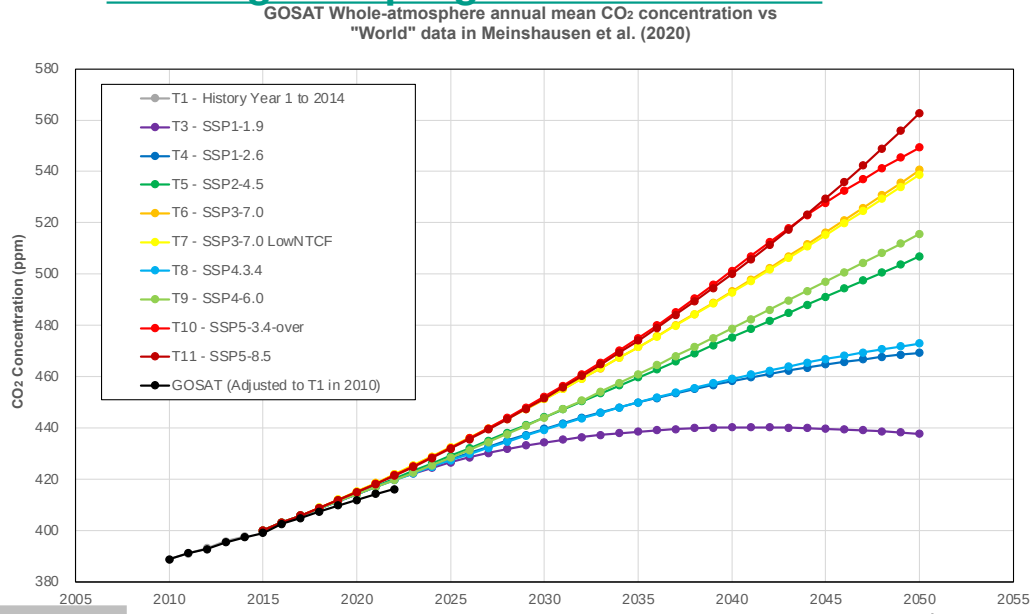
- requires installation of **many sampling sites**
- difficult to measure at **high altitudes**

Satellite observation from the earth's surface to the top of the atmosphere worldwide is a valuable method

Long-term, global concentration data



Use in global progress assessment



Graph: NIES

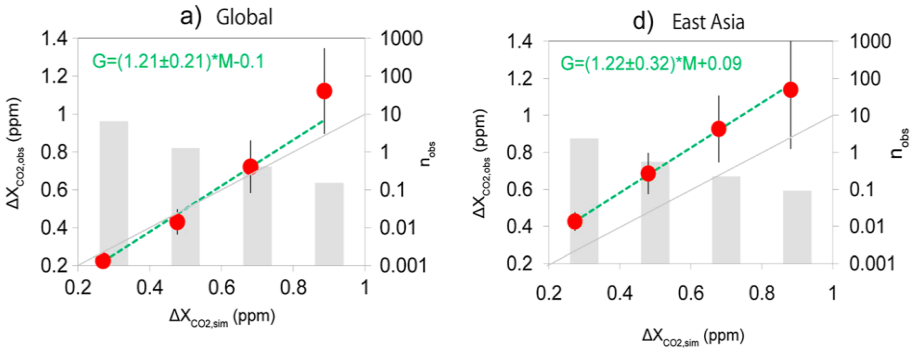
GOSAT series will continue to provide long-term, global observation data to the world

Major GOSAT Series Achievements: National to Continental Level Observation (CO_2)

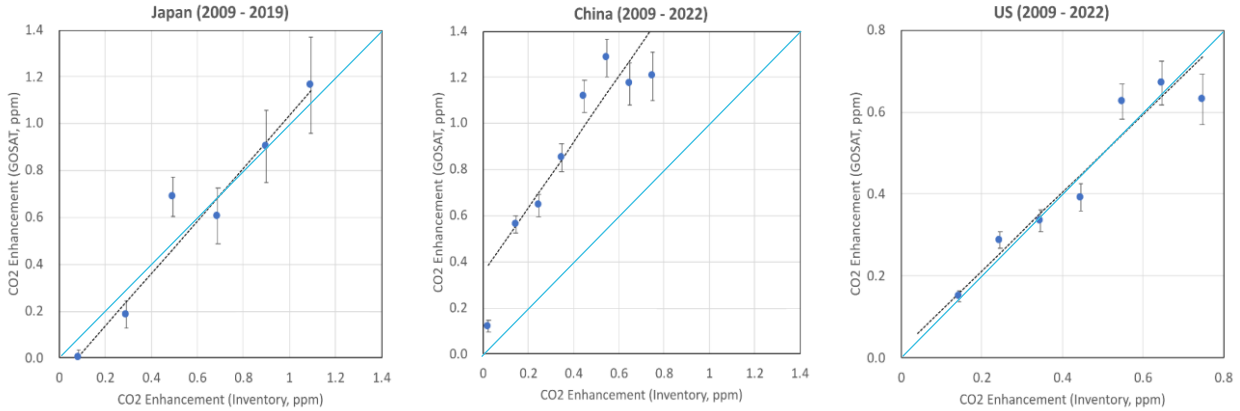
■ MOE is advancing research that compares **data from the GOSAT series** with **GHG emissions estimated based on statistics**, or **emission volumes reported by each country to the UNFCCC**. This effort contributes to improving the **transparency of emission reporting** by each country.

CO_2 emissions 【Janardanan et al.(2016)】

- Compared distribution on maps of GOSAT observation values and values predicted from fossil fuel consumption volume, power plant sites, and other statistical data
- Analysis results for "Global," "Northern Hemisphere," "Eurasia," and "North America" regions are aligned within the margin of error. "East Asia," however, is further upward than the straight line with a slope of 1 **(vertical axis (GOSAT observations) > horizontal axis (statistical data)). (Left two graphs)**



Comparison of increase in concentration due to carbon dioxide emissions originating from fossil fuels in each region (vertical axis: GOSAT observations, horizontal axis: emission source database ODIAC) [Excerpt from Janardanan et al. (2016)]



Comparison of CO_2 anthropogenic emissions based on Janardanan et al. (2016) for satellite observations (GOSAT) and ODIAC statistical values (Japan, China, US) [Source: NIES]

(Note) In the second graph, the increase in anthropogenic carbon dioxide concentration obtained from GOSAT series observations is about 1.5 to 3 times larger than the increase in anthropogenic carbon dioxide concentration obtained from statistics. However, this analysis includes only the relatively low concentration data (0.2 ppm-1.0 ppm), for which a large number of data were available. As those low concentration data could be affected strongly by vertical shifts of the graph, which tend to be caused by data correction and statistical procedures, it is not possible to discuss the emissions from the entire country based on this data with high constant (i.e. y-intercept).

Cause of East Asia's difference

Research by Guan et al. (2012), Liu et al.(2015), and research using recent ground observations by Zhong et al.(2023) and others, show a tendency of observation values to be higher than statistical values in China.

Additional analysis 【further analysis using the Janardanan et al.(2016) method】

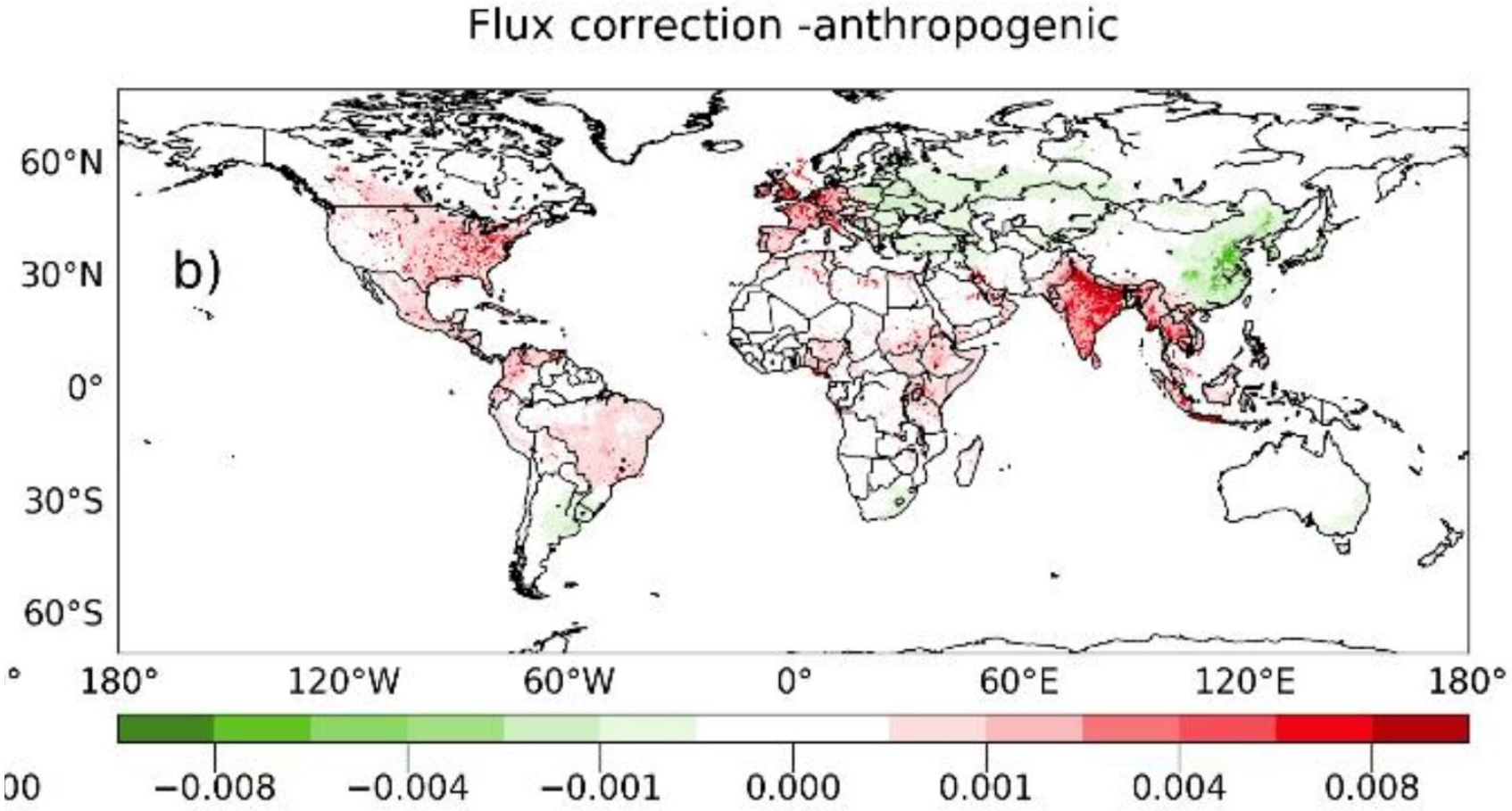
This analysis was conducted with GOSAT observation data and statistical values for Japan, China and the US. It suggested, as many of the above-mentioned papers did, that the statistical values were possibly lower than observed in China. **(Right three graphs)** See the note of the right three graphs for the interpretation of the data.

Major GOSAT Series Achievements: National to Continental Level Observation (CH_4)

Methane emissions 【Janardanan et al.(2020)】

- This conducts mapping of difference between anthropogenic emissions estimates from GOSAT data and a priori emission values based on statistical data, etc. (Green: Regions with smaller observation values than a priori values; Red: Regions with larger observation values than a priori values) (Lower graphs)
- However, it has been confirmed in country-level detailed analysis that these are all within measurement error scope.

Future analysis will improve precision including GOSAT-GW additional data



Difference between GOSAT estimates and a priori values for methane anthropogenic absorption and emission levels [excerpt from Janardanan et al (2020) fig.3]

Major GOSAT Series Achievements: National to City/Regional Level Observation

- The government of Japan provides support toward efforts to confirm GHG emissions based on **detailed information, ground-level observations, sonde observations**, etc. and **compare them with data from the GOSAT series**, in developing countries that have a desire to enhance the transparency of their GHG emissions reporting.
- **The Mongolian government reported to UNFCCC in its BUR2** in November 2023 that it found **"excellent agreement"** between emission estimates based on **GOSAT and domestic annual emission estimates**.
- The GOSAT series contributes to promoting **emission estimates in cities**, which account for approximately 70% of global greenhouse gas emissions and two-thirds of global energy consumption, and efforts to observe and estimate methane emissions from specific regions.

Country-level CO_2 emission estimate in Mongolia 【Watanabe et al.(2023)】

Calculated CO_2 emissions by Mongolia's energy sector utilizing GOSAT satellite data

- GOSAT-based emission estimates and Mongolia's 2018 emission estimates aligned within a 1.5% margin
- 4.2% lower in a comparison with "The Emissions Database for Global Atmospheric Research (EDGAR)"

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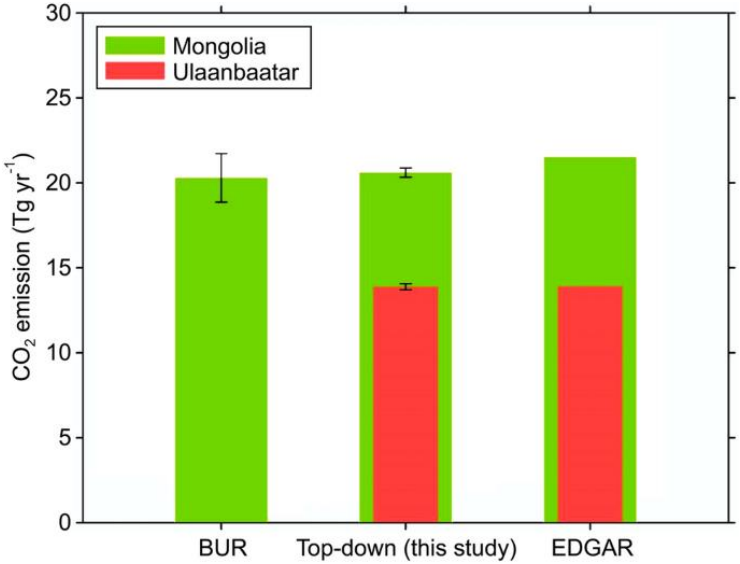


Comparison of estimations of carbon dioxide emissions from Mongolia and the capital city of Ulaanbaatar based on BUR (left), GOSAT (center), and the database (EDGAR) calculated from publicly available statistics [Excerpt from Watanabe et al. (2023)]

City-evel CO_2 emission estimates 【Kuze et al.(2022)】

Estimated CO_2 emissions from six major cities (Beijing, Tokyo, New York, etc.) using GOSAT data and compared results with inventory prepared from fossil fuel consumption volume

- Indicates that **GOSAT data can be utilized to estimate emissions by major cities**
- Reduction of variation and bias in estimates requires increase clear-weather data volume and separation of background from simultaneous measurement of nitrogen dioxide (NO_2) emitted by high-temperature combustion of fossil fuels

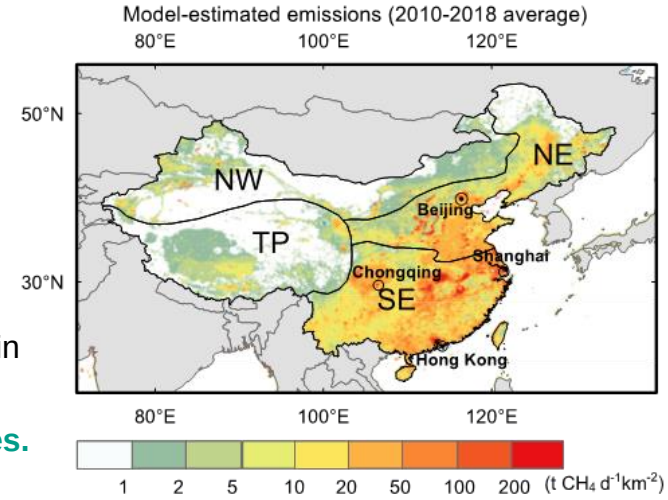
Major GOSAT Series Achievements : National to City/Regional Level Observation

Estimated methane emissions in China

【Wang et al.(2022)】

This work analyzed methane emissions from multiple regions in China during 2010-18 based on GOSAT data and ground-level GHG observation data.

- In particular, in the Northeast region of China (NE in the figure), which has an upward trend in methane emissions in recent years, annual fluctuation of total emissions of methane derived from GOSAT data changes in line with emissions estimated from statistical values, including differences in natural gas usage, sales volume, and purchase volume in the region.
- There is concerns about **leaks of natural gas in production, transport, and consumption stages.**



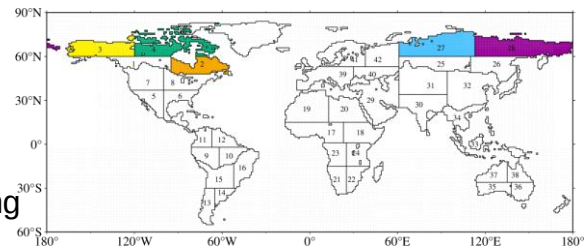
[Excerpt from Wang et al.(2022)]

Monitoring methane emissions by high-latitude regions in the Northern Hemisphere

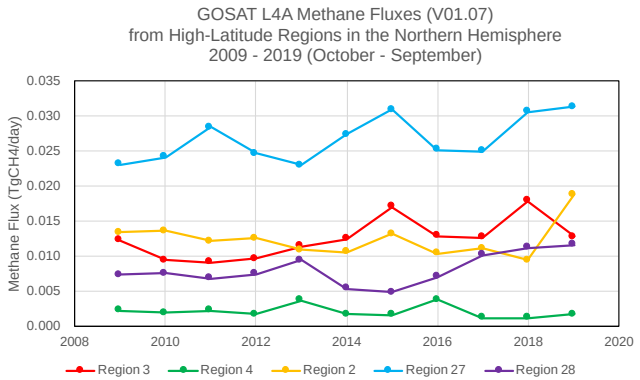
【NIES web site】

"There is a high probability of further increases of atmospheric concentrations of CO2 and CH4 due to irreversible carbon emissions from permafrost thaw and CO2 and CH4 fluxes from wetlands, permafro thaw and wildfires." (IPCC AR6 WG1 report)

In the data gallery for the GOSAT L4 product, NIES discloses time-series data of carbon dioxide and methane emissions estimated from global observation results, including regions with permafrost, and monitors changes in emission volumes that could potentially occur in the future.



Annual average methane emissions in Northern Hemisphere high-latitude regions (October through September of the following year)



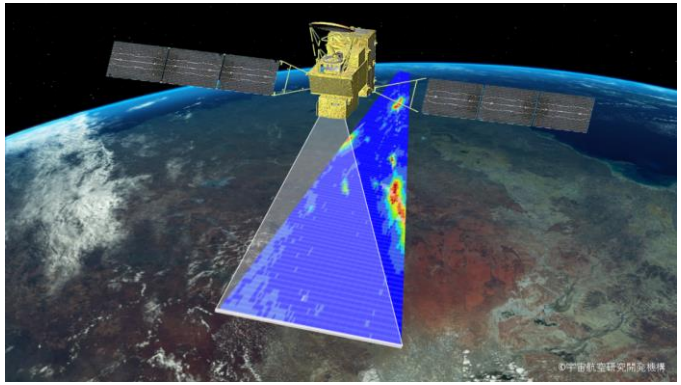
Efforts to enhance observation precision of the GOSAT series

- One effort is analysis and calibration utilizing observation data from ground-level monitoring devices, ships, and airplanes.
- Joint observations with the NASA, ESA, and other space agencies are taking place too.
  JAXA implements a joint field campaign annually in Nevada (the U.S.) to confirm precision by making observations and comparing data at the same time and same location by five satellites (including the GOSAT series).
- Data from Europe's TROPOMI satellite is corrected using GOSAT.

Joint observations by NASA, ESA, and JAXA in Nevada（from the JAXA website ）

Future issues and initiative policy

- Japan plans to launch GOSAT-GW, the third satellite in the GOSAT series, in FY2024, and also considers a successor satellite for the 2030s.
- JAXA conducts joint observations with NASA, ESA to enhance data quality. Japan promote installations of observation devices in developing countries and data disclosure.
- MOE intends to expand methodology to estimate country-level emissions developed in Mongolia to other regions such as Central Asia, India, the Himalayan region, the Caucasus region, and Asia.
- MOE will provide observation data from the GOSAT series to private-sector to promote commercial uses.



GOSAT-GW TANSO-3 (wide-area observation mode)

【GOSAT-GW overview】

- **It observes GHGs as well as water cycles, including precipitation distributions** and carries two instruments onboard: Total Anthropogenic and Natural Emissions monitoring SpectrOmeter-3 (TANSO-3) and Advanced Microwave Scanning Radiometer 3 (AMSR3).
- Sensors have been changed to performs **surface-based observation** rather than point-based observation
- It has two modes - **Wide Mode with 911km observation width (10km*10km resolution) and Focus Mode with 90km observation width and 3km*3km spatial resolution (target resolution of 1 km*1km)**
- **It observes NO_2, in addition to CO_2 and methane**
- Utilizing **data that is 100-1,000 times the amount provided by GOSAT-2**, it will provide more precise estimates of country-level emissions

Contributions to the Scientific Community

- Contribute to improved measurement of global GHGs using GOSAT observation data
- Contribute to the scientific community, including the process for preparation of the IPCC's 7th report

Utilization to Climate Policy

- Strengthen collaboration with partner countries to expand application of the estimation method of Mongolia to India, the Himalayan region, the Caucasus region, and Asia, from FY2024,
- Contribute to transparency of GHG reporting by support to include verification results using the GOSAT series in country-level reports to the UNFCCC.

Commercial Uses

- Enhance the reliability of information on corporate climate actions by using GOSAT observation data.
- Enhance investments in truly climate-aligned projects through avoiding green wash and divestment from projects with large emission.

Provide a scientific data to support objective estimation and further actions

Contribute to emission reduction/increase absorption aiming at a Net Zero in 2050

Initiative to prevent GOSAT satellites from becoming space debris

- Space debris have increased in recent years and is a concern for continuous safe operation of space.
- MOE Japan has a responsibility for appropriate operation and disposal as one of the entity in charge of the GOSAT series. MOE Japan has been addressing the issue of preventing the satellites from becoming space debris. It formed a team within the Ministry in March 2020 and published an interim report in October 2020.
- GOSAT continues to operate properly and is not facing functional issues. MOE Japan prepares for unexpected incident which may affect GOSAT series in collaboration with stakeholders.

"Future Effort of Ministry of the Environment to Address Space Debris Issues" (Interim Summary) (October 2020)

- Measures to prevent existing satellites from becoming space debris are delegated to autonomous initiatives based on domestic and overseas regulations and guidelines.
- GOSAT proactively applies and adheres to these, and the MOE is a leader in disclosure of review procedures to the world.

❶ Even if a satellite is still usable beyond its design life,
❷ After the mission of GOSAT has been successfully taken over by GOSAT-2、
❸ With the understanding of stakeholders and data users,
❹ Following discussions by the MOE, NIES and JAXA, they should start disposal process at an appropriate timing

Progress so far

Current status❶

- **GOSAT-1 continues to operate properly currently**.
- Regarding evaluation of satellite soundness, the premise of continued operation, JAXA annually evaluates soundness, including the prospect a year later, based on Space Debris Mitigation Guidelines (JMR-003E) that reflect revisions from the 2019 version of ISO24113, the latest international rules. The most recent evaluation at the end of March 2023 confirmed that the conditional reliability of functions required for disposal process is not less than 0.9. This means that it is **not facing functional issues**.

Current status ❷

- In September 2023, Yoshida, et al (2023) examined the extent to which systematic differences that may exist in CO2 and CH4 concentration data between satellites vary over time and space by comparing CO2 and CH4 concentration data obtained from the GOSAT and GOSAT-2 satellites and found that they generally agree to within 1%.
- Based on this result, it is possible to conclude that **GOSAT-2's succession of the GOSAT observation mission was completed as of September 2023**.

Current status ❸

- In scientific research, GOSAT data is still more frequently used than GOSAT-2 data. (Use of GOSAT-2 is expected to increase due to guarantee of continuity between long-term data supplied by GOSAT by Yoshida et al. (2023).
- In the context of climate policy, GOSAT-2 data could be utilized after many developing countries submit their GHG emission of the term after GOSAT-2 launched.
- **Replacement to GOSAT-2 is not yet complete among data users.**

Current status ❹

- Based on these points (1-3), **now is not the time to proceed with a detailed consideration of disposal measures.**
- Nevertheless, the MOE intends to proceed with preparation of an action plan for deorbiting and suspended operation as readiness to address unexpected risk of GOSAT becoming space debris and **reviews and coordination via periodic discussions** with NIES and JAXA.