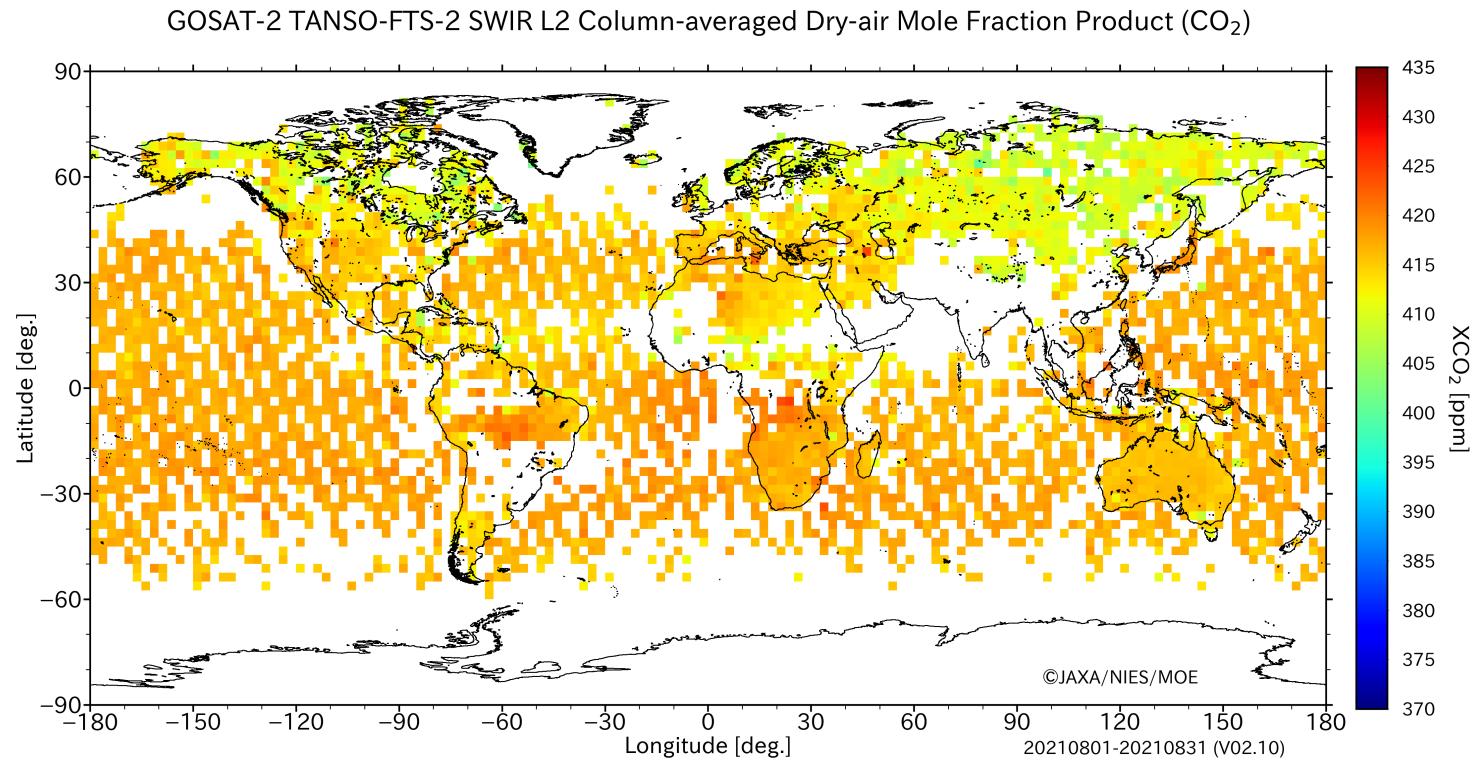




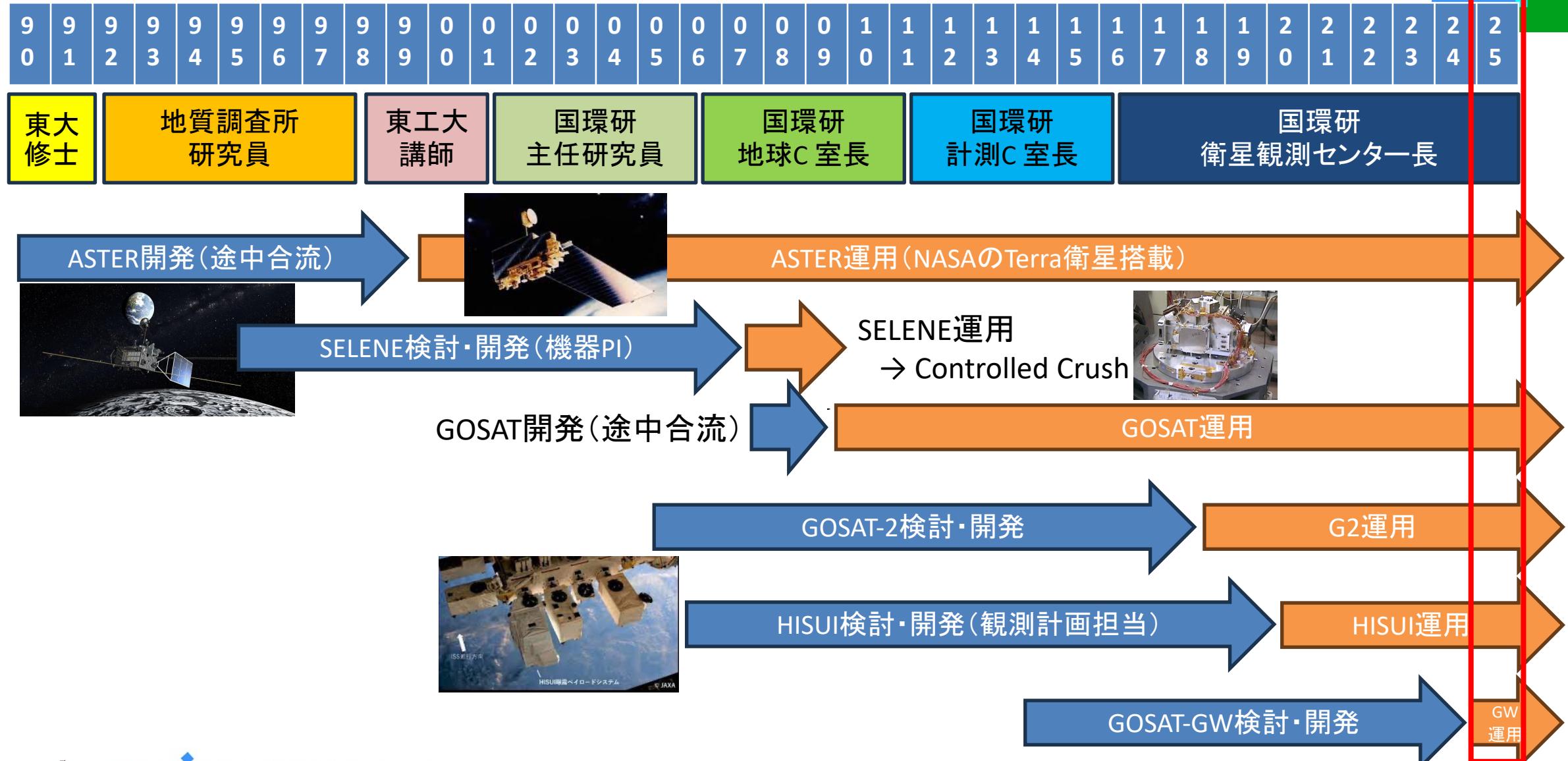
GOSATシリーズによる全球温室効果ガスモニタリング

Global Greenhouse Gas Monitoring by GOSAT Series

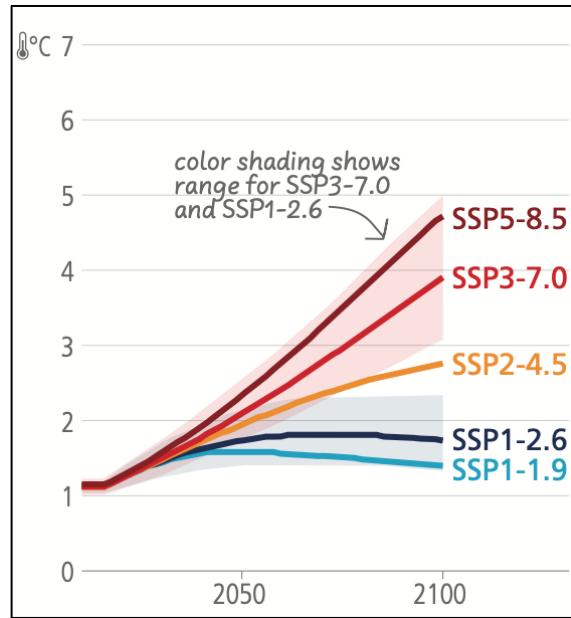
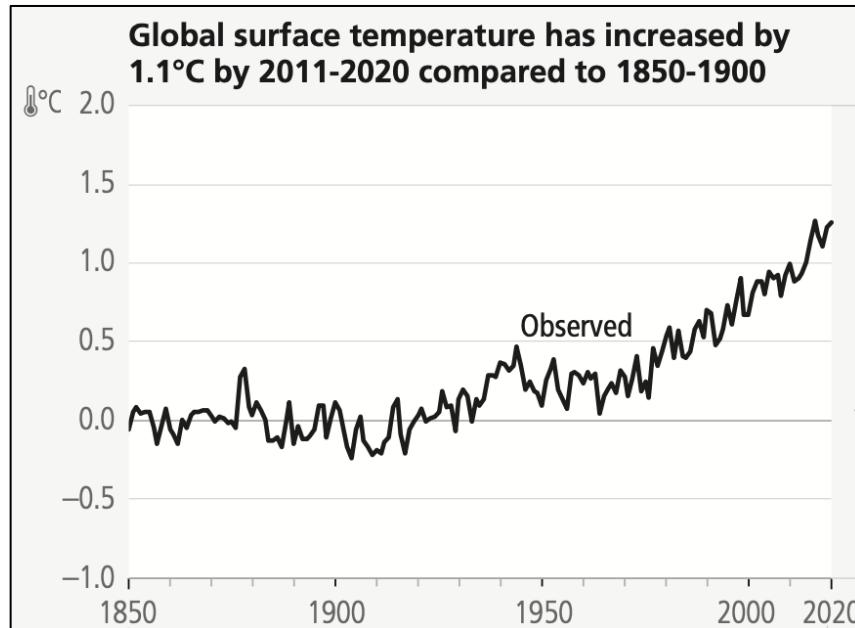


国立環境研究所 衛星観測センター
松永恒雄

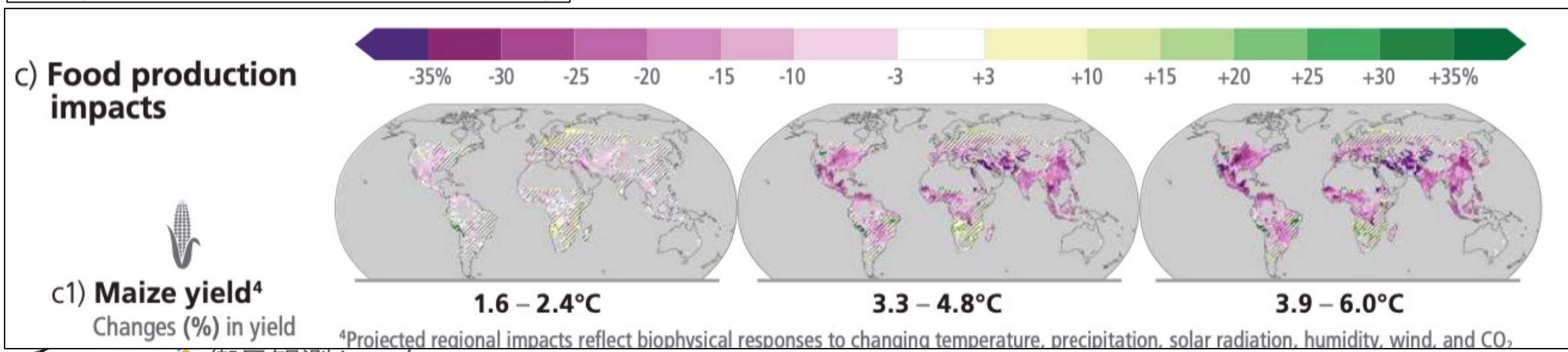
松永の経歴と従事した衛星プロジェクト



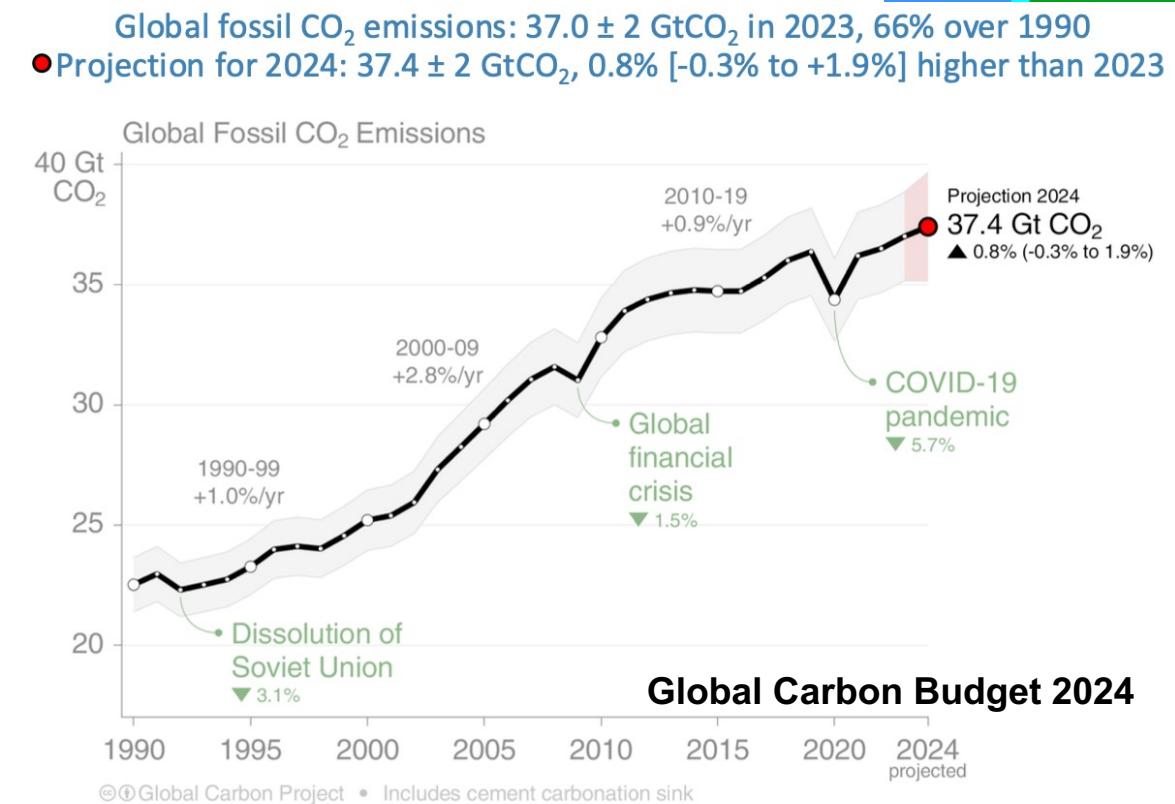
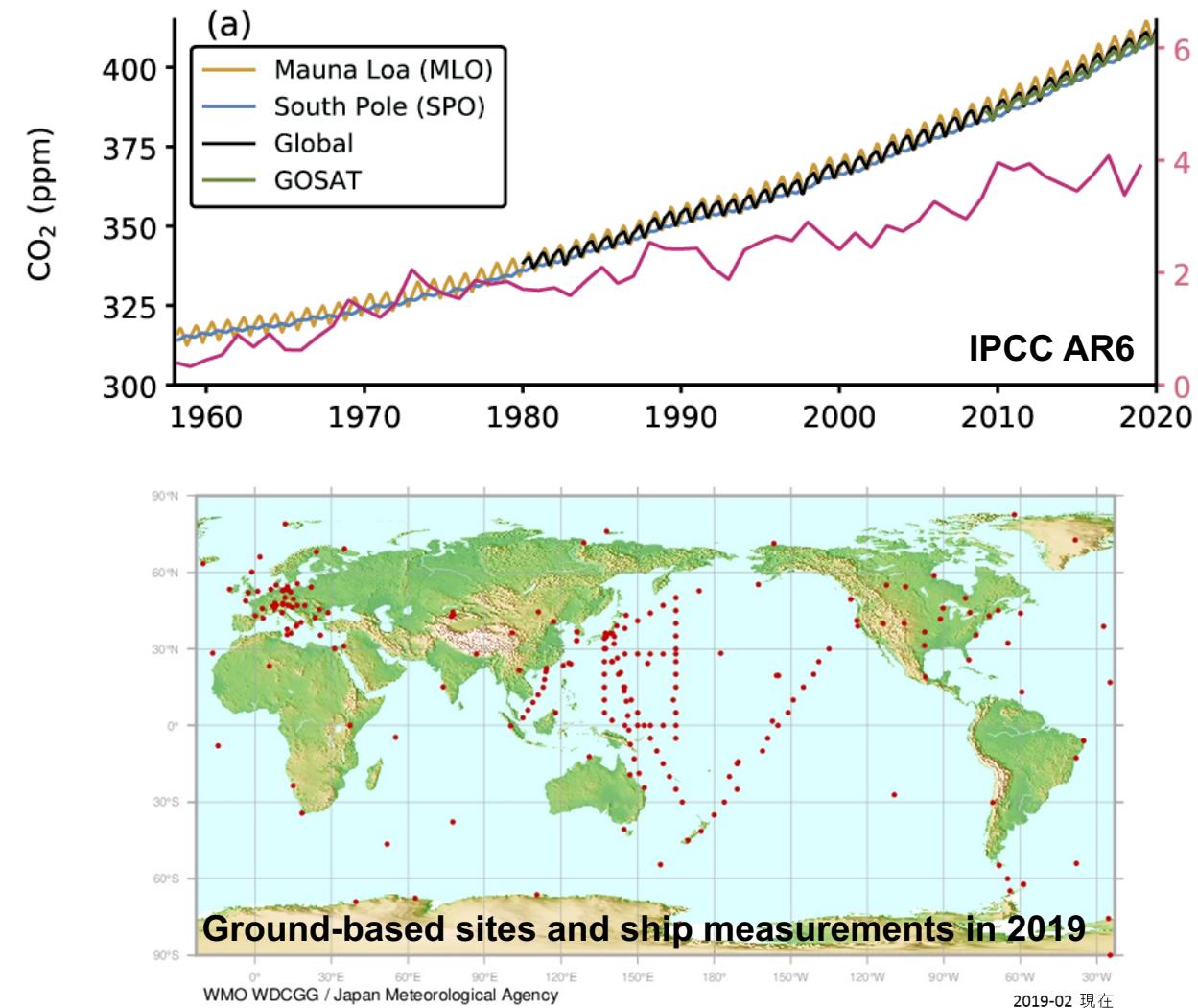
Current and Future Climate Change (IPCC AR6 Synthesis Report, 2023)



- Global temperature has increased by 1.1 deg C by 2011-2022 compared to 1850 – 1900.
- 4 - 5 deg C increase is predicted in the worst-case scenarios.
- Future climate change is projected to increase the severity of impacts across natural and human systems including food production.

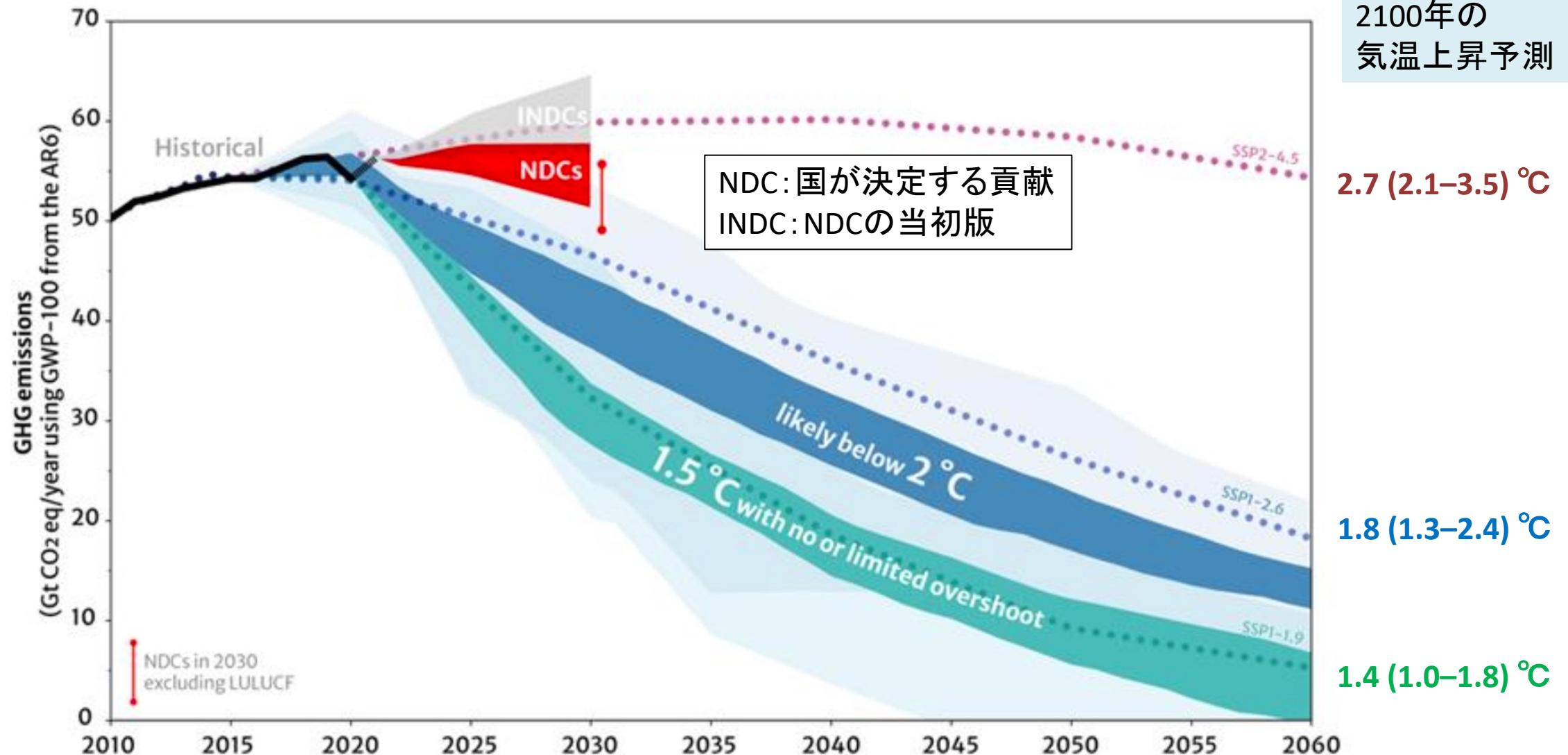


Current Status of CO₂



- ✓ GHG concentrations and emissions are still increasing.
- ✓ Need to stabilize GHG concentration ASAP to keep 1.5 deg target in the Paris Agreement.
- ✓ Need to evaluate global and country-wise GHG emissions.
- ✓ More GHG data are required for emission evaluations.
- ✓ But ground-based GHG measurement sites are so sparse...

2010年以降の温室効果ガス排出量の推移： 過去の報告値・NDCに基づく予測値・IPCCシナリオの想定値



<https://unfccc.int/documents/619180>

What is GOSAT Series ?

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 | 2032 | 2033 |
|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|

▲Paris Agreement

▲IPCC AR4

▲1st GST

▲IPCC AR5

▲IPCC AR6

▲2nd GST

▲IPCC AR7

▲3rd GST

Development

Nominal Operation

Extended Operation

GOSAT

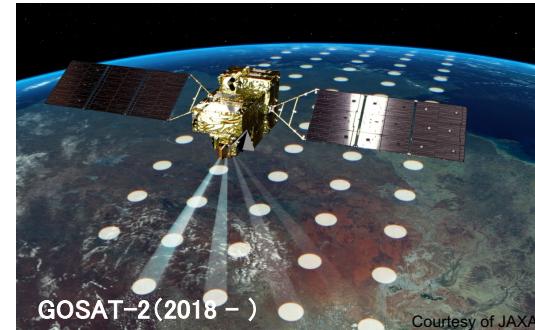


Development

Nominal Operation

Extended Operation

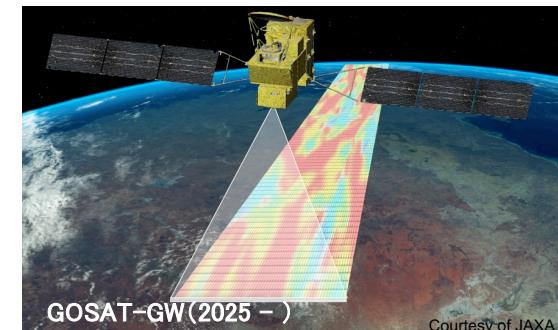
GOSAT-2



Development

Nominal Operation

GOSAT-GW



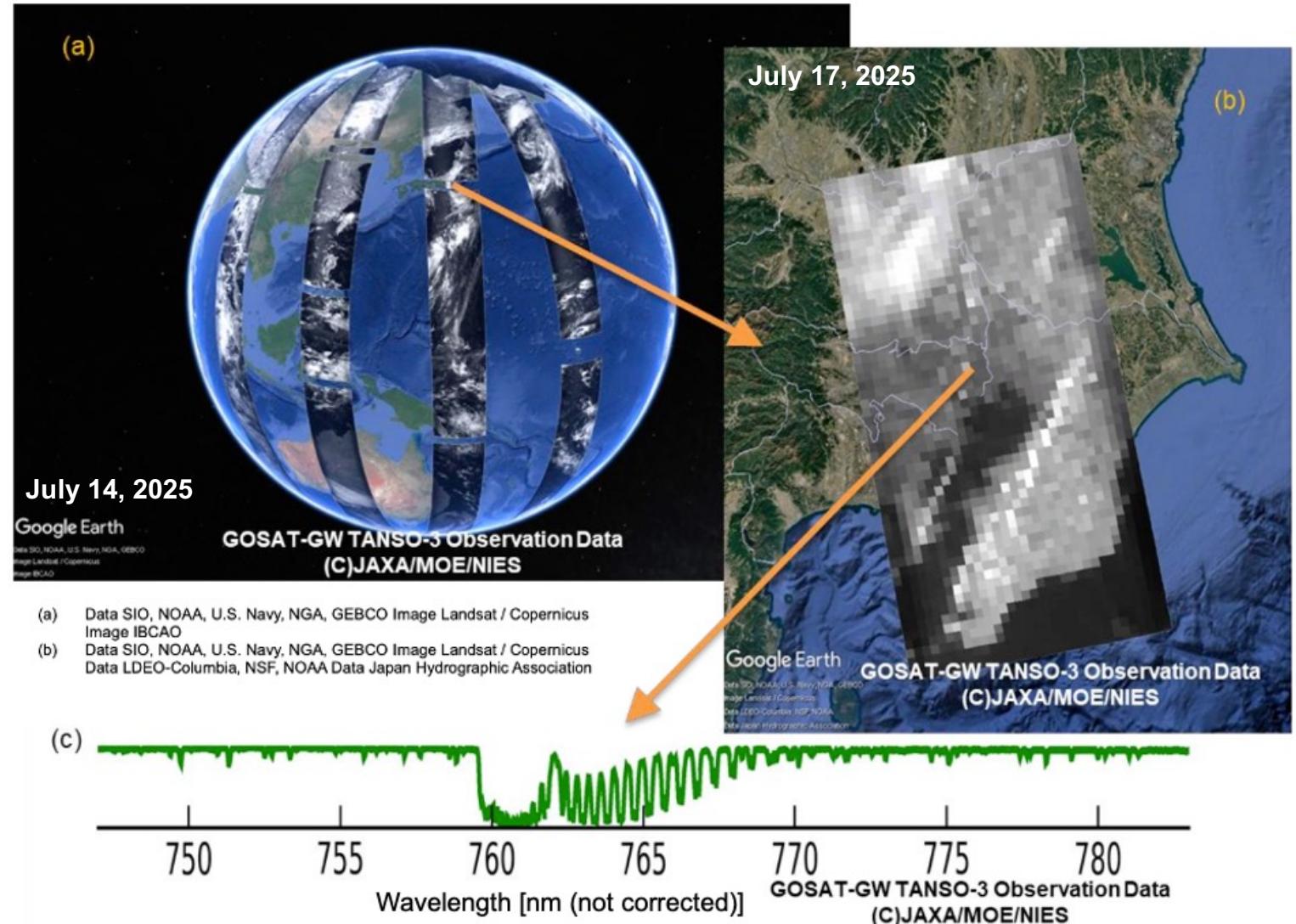
GOSAT-GW was successfully launched on June 29, 2025.

GOSAT-4?

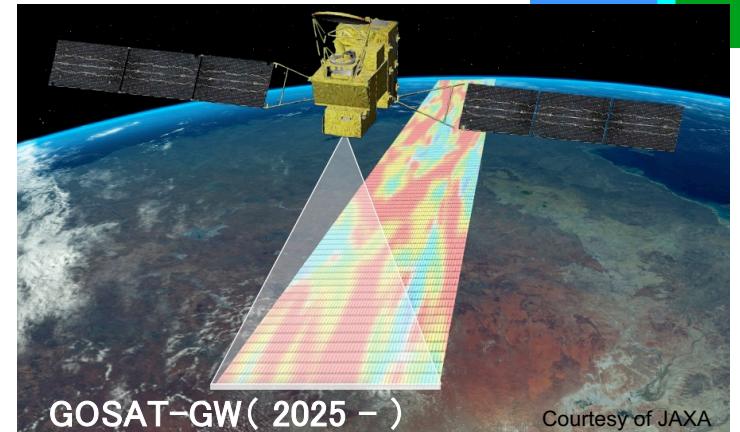
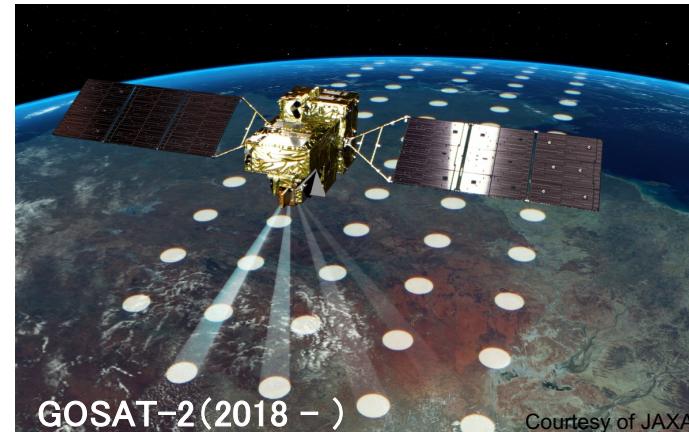
GOSAT Series is Japanese earth observation satellites with high spectral resolution spectrometers for the global monitoring of greenhouse gases. More than 16 years of GHG data have been acquired so far.

- **GOSAT** (2009 -) Fourier transform spectrometer (FTS) for CO₂ and CH₄
- **GOSAT-2** (2018 -) FTS-2 for CO₂, CH₄, and CO
- **GOSAT-GW** (2025 -) Grating imaging spectrometer (TANSO-3) for CO₂, CH₄, and NO₂
- Joint projects by MOE, NIES, and JAXA

Successful Launch of GOSAT-GW and First Light of TANSO-3



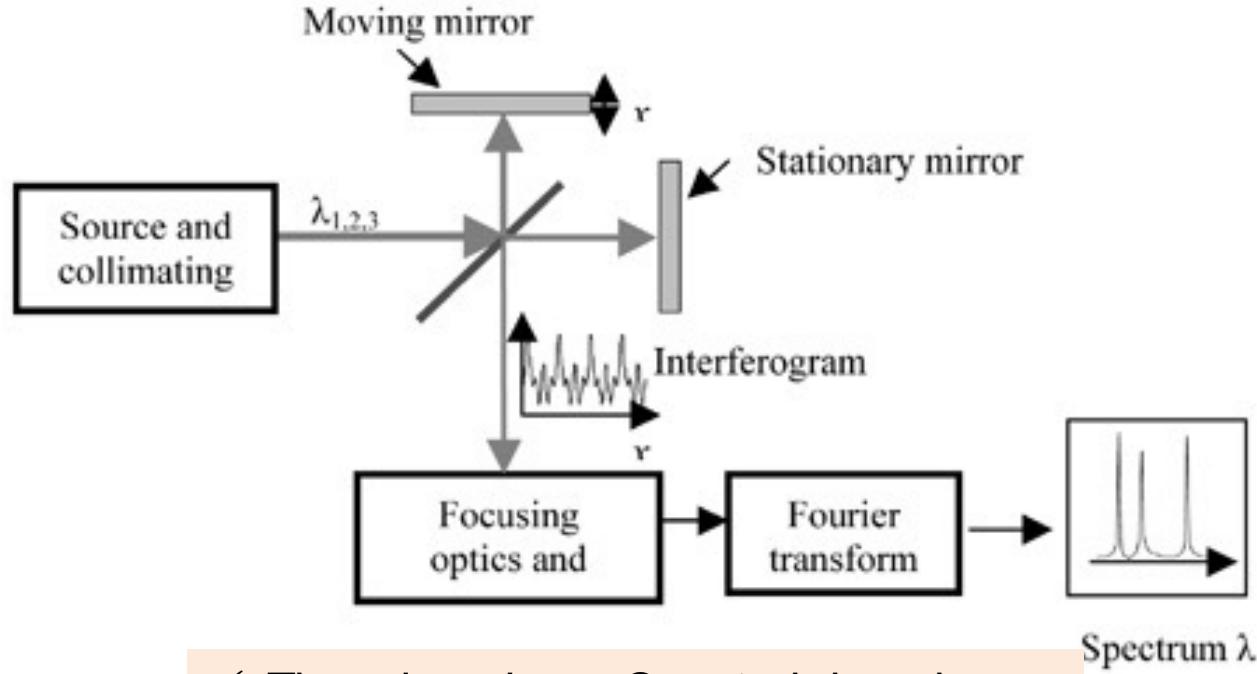
GOSAT、GOSAT-2、GOSAT-GWの主な仕様(温室効果ガス関係)



| | GOSAT | GOSAT-2 | GOSAT-GW |
|---------------------|--|---|--|
| 打上げ年 / 設計寿命 | 2009 / 5 年 | 2018 / 5 年 | 2024年度 / 7 年 |
| 衛星の重量 / 電力 | 1.75 t / 3770 W | 1.8 t / 5000 W | 2.9 t / 5200 W |
| 軌道 | 高度666 km, 3日回帰, 赤道通過時刻13:00, 降交軌道 | 高度613 km, 6日回帰, 赤道通過時刻13:00, 降交軌道 | 高度666 km, 3日回帰, 赤道通過時刻13:30, 昇交軌道 |
| 分光計 | FTS(フーリエ変換分光計) | FTS-2 | TANSO-3 (Grating(回折格子)) |
| 観測対象気体 | CO ₂ , CH ₄ (二酸化炭素とメタン) | CO ₂ , CH ₄ , CO(一酸化炭素) | CO ₂ , CH ₄ , NO ₂ (二酸化窒素) |
| 観測波長帯 | 0.7 / 1.6 / 2 μm + TIR(熱赤外) | 0.7 / 1.6 / 2 μm + TIR | 0.45 / 0.7 / 1.6 μm |
| 波長分解能 (サンプリング間隔) | 0.2 cm ⁻¹ , (≈ 0.01 nm @ 0.7 μm, ≈ 0.05 nm @ 1.6 μm) | | < 0.5 nm @ 0.45 μm, < 0.05 nm @ 0.7 μm, < 0.2 nm @ 1.6 μm |
| 刈り幅 | 離散的, 1 – 9 points | 離散的, 5 points | 911 km (広域モード)、90 km (精密モード) |
| 直下視の場合の視野サイズ | 10.5 km | 9.7 km | 10 km (広域モード)、1 – 3 km (精密モード) |
| ポインティング機能 | ±20 / ±35 度 (衛星進行方向(AT)/その直交方向(CT)) | ±40 / ±35 度 (AT/CT) インテリジェントポインティング | ± 40 / ± 34.4 度 (AT/CT) |
| 同時搭載機器 | CAI (雲・エアロソルセンサ) | CAI-2 (雲・エアロソルセンサ2型) | AMSR3 (高性能マイクロ波放射計3) |

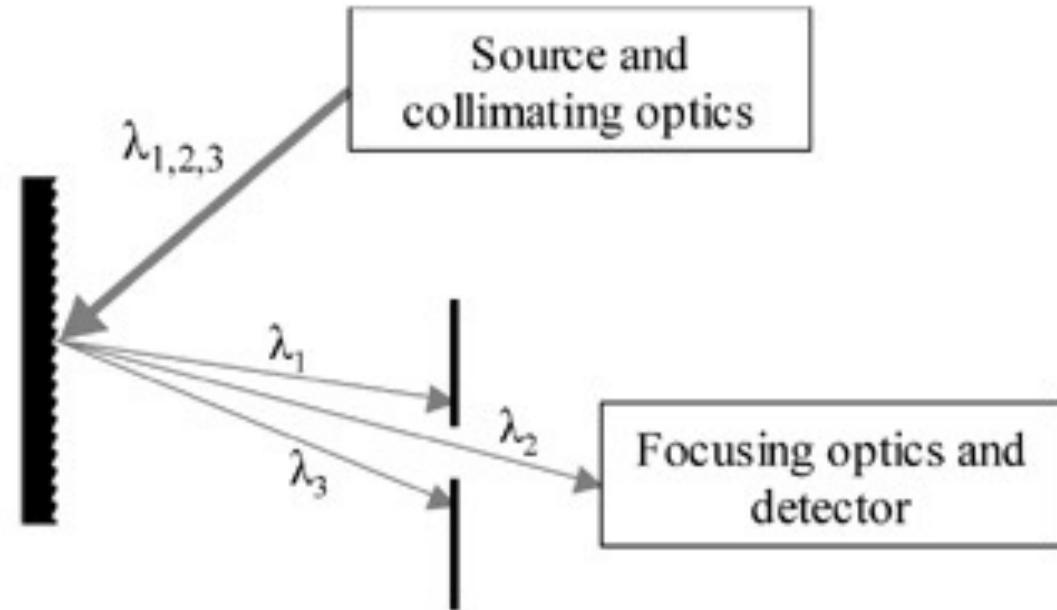
Spectrometers used for column GHG measurement from space

Fourier Transform Spectrometer



- ✓ Time domain => Spectral domain
- ✓ High spectral resolution
- ✓ Easy to extend the spectral coverage
- ✓ Moving parts
- ✓ Difficult to obtain images
- ✓ GOSAT and GOSAT-2

Grating Spectrometer



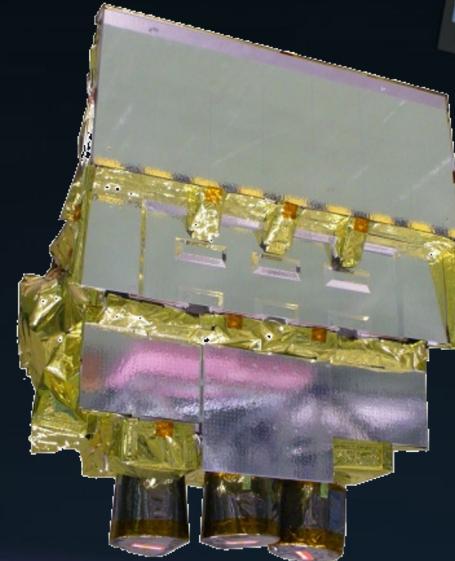
- ✓ Spatial domain => Spectral domain
- ✓ Low spectral resolution
- ✓ Difficult to extend the spectral coverage
- ✓ No moving parts
- ✓ Easy to obtain images
- ✓ OCO-2, TROPOMI, and GOSAT-GW

GOSATと搭載センサ(TANSO-FTSとTANSO-CAI)

衛星本体

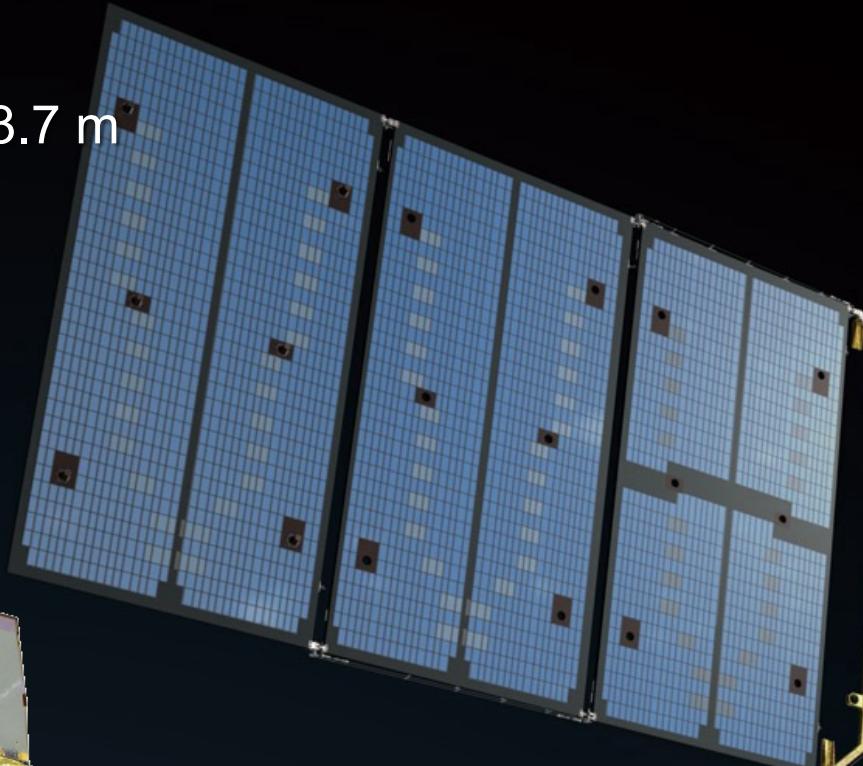
1.75 t

2.0 m x 1.8 m x 3.7 m



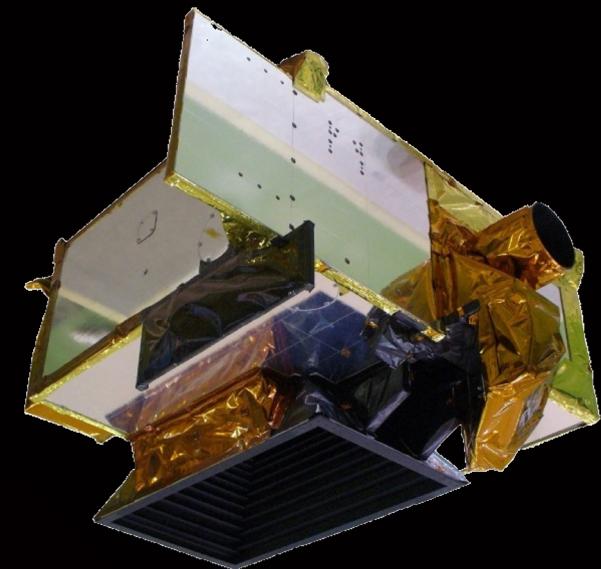
TANSO-CAI

雲・エアロゾルセンサ
(雲やエアロゾルの空
間分布を撮影する。)

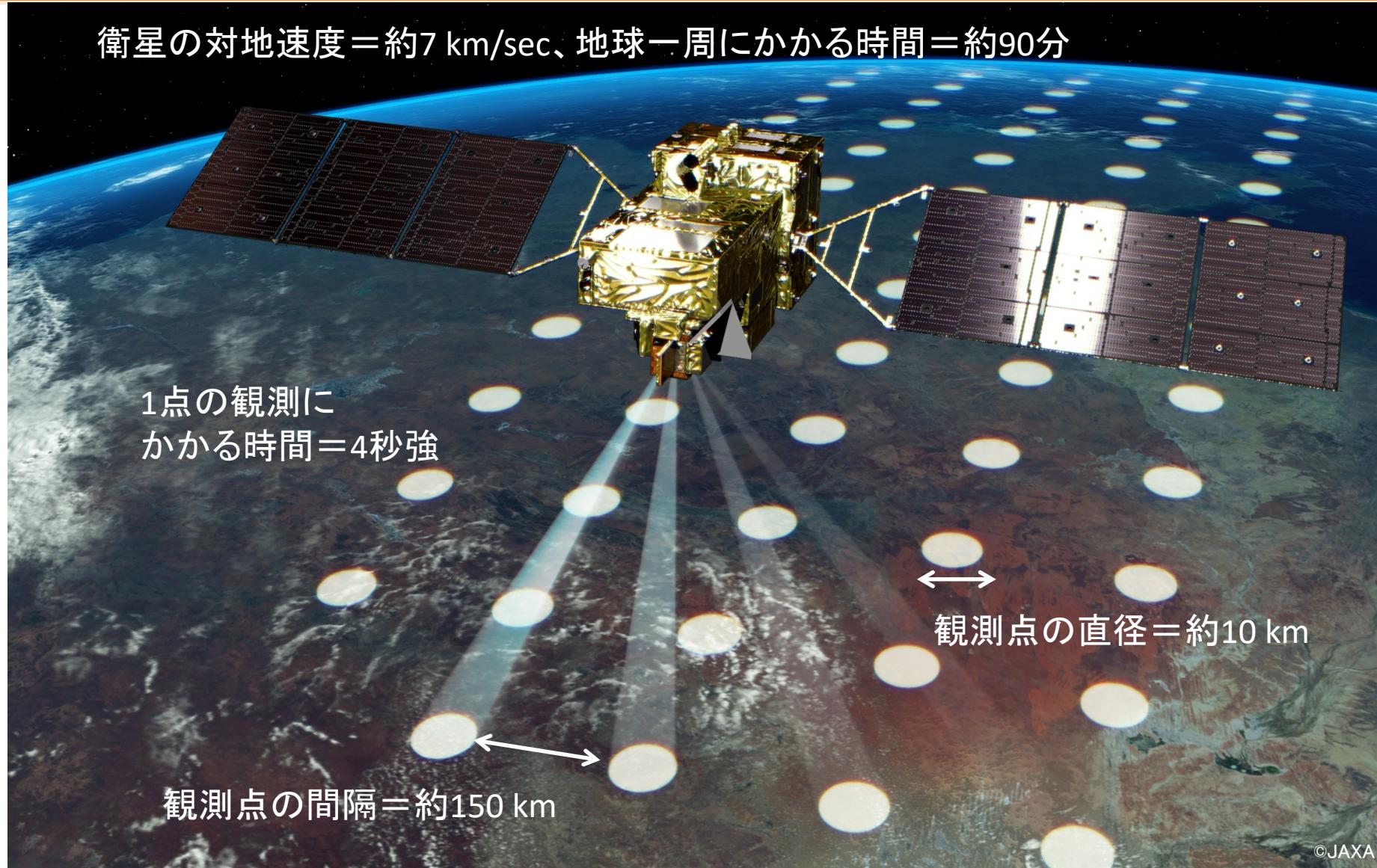


TANSO-FTS

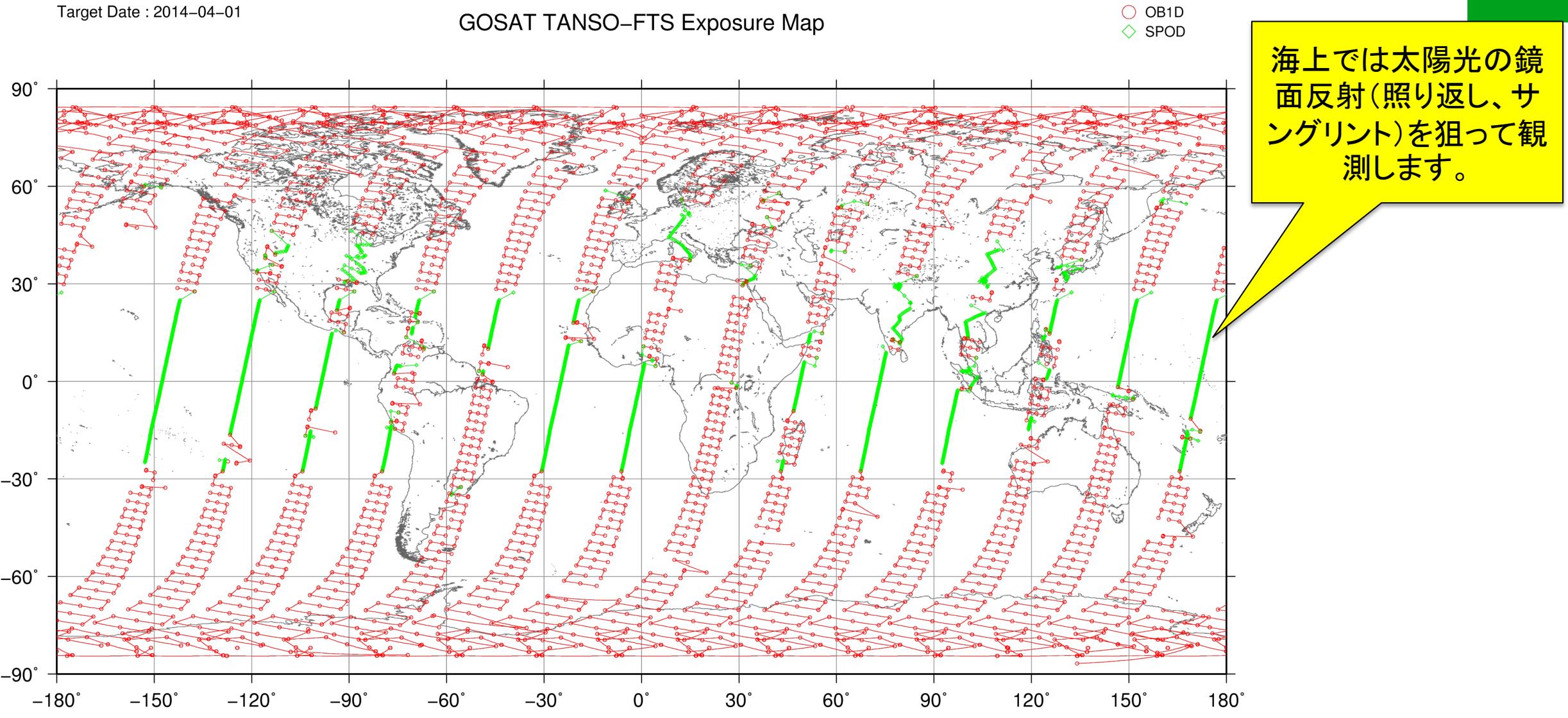
フーリエ変換分光計
(二酸化炭素などの
濃度を測定する。)



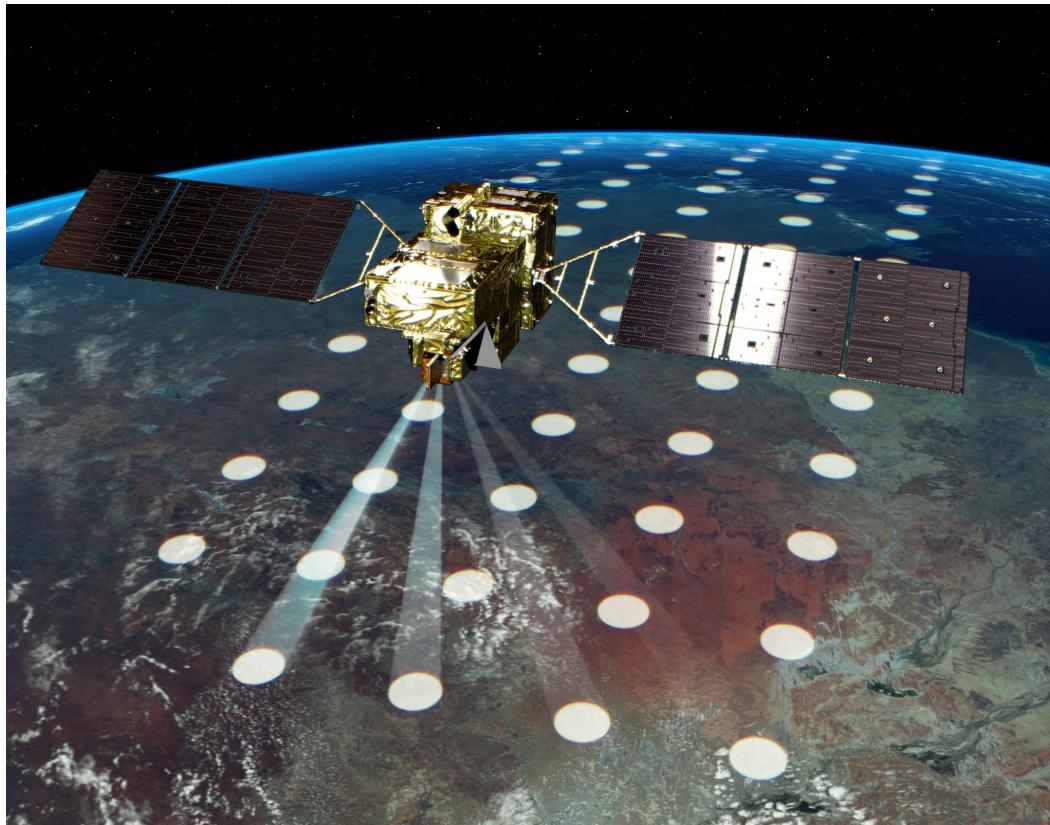
温室効果ガス観測技術衛星2号(GOSAT-2)の観測の様子



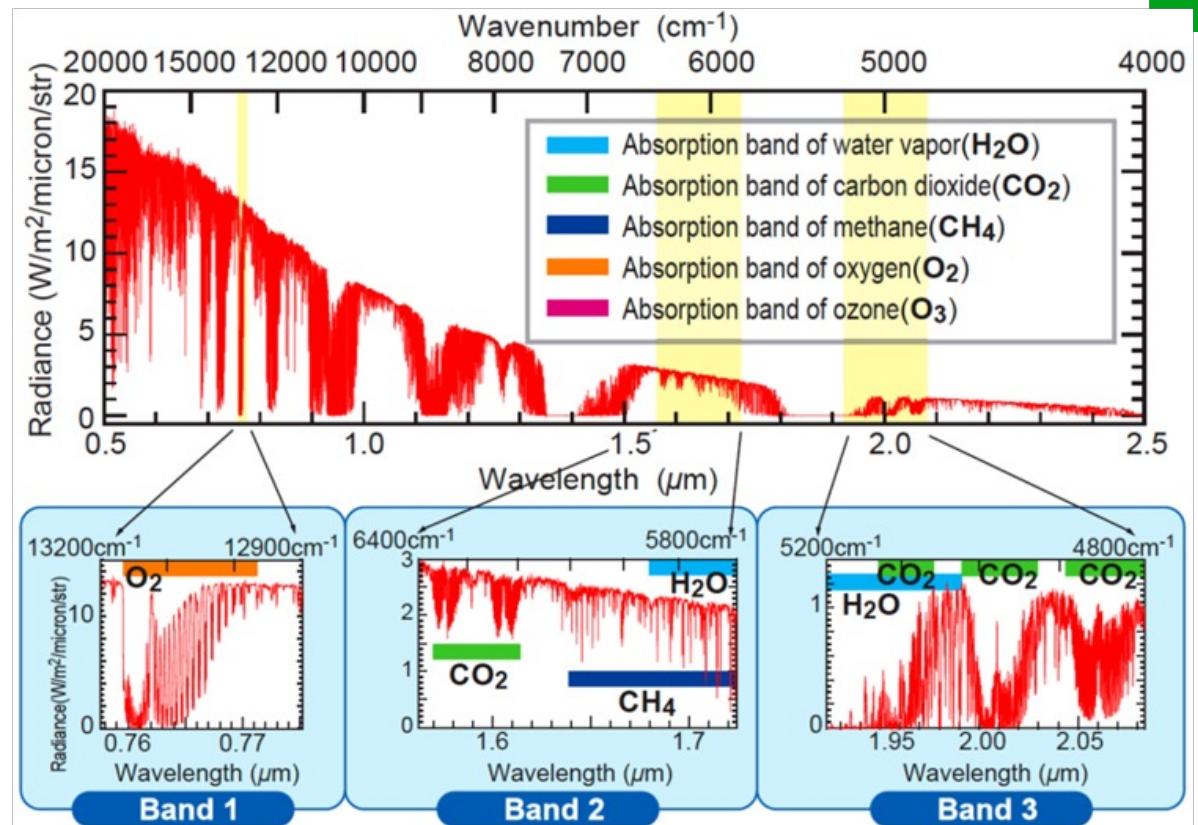
実際のGOSATの観測点の分布: 2014/4/1(昼)の例



How to measure GHG concentrations from satellites



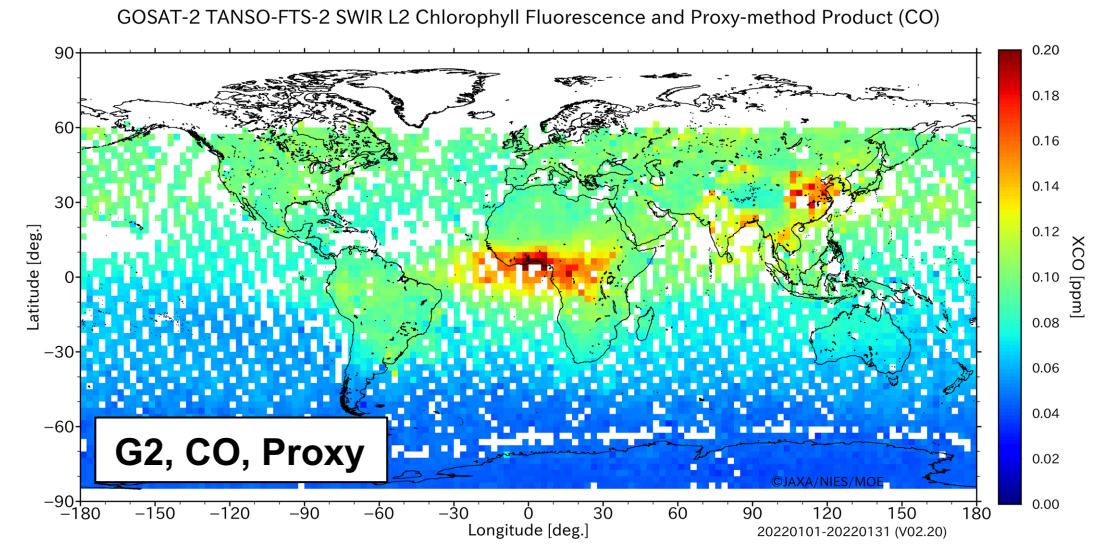
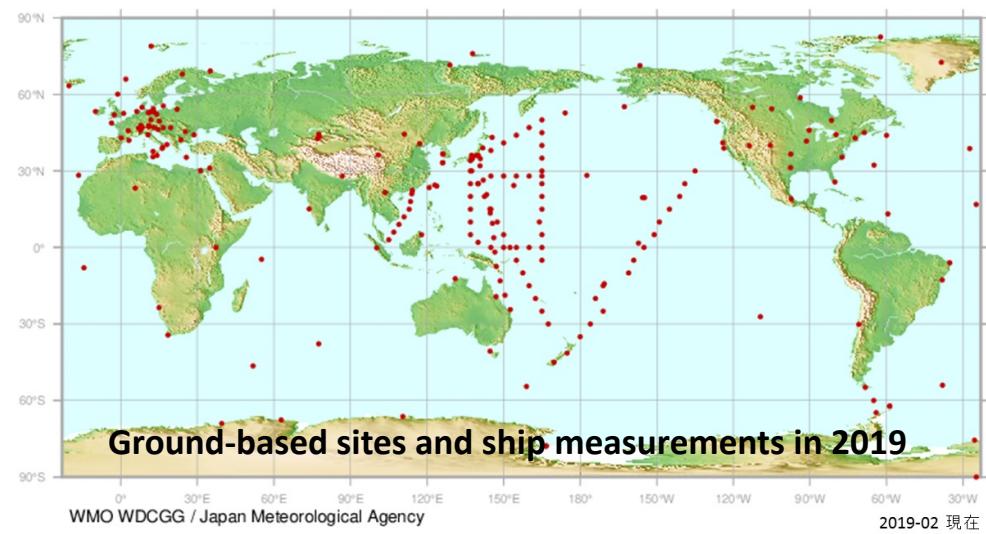
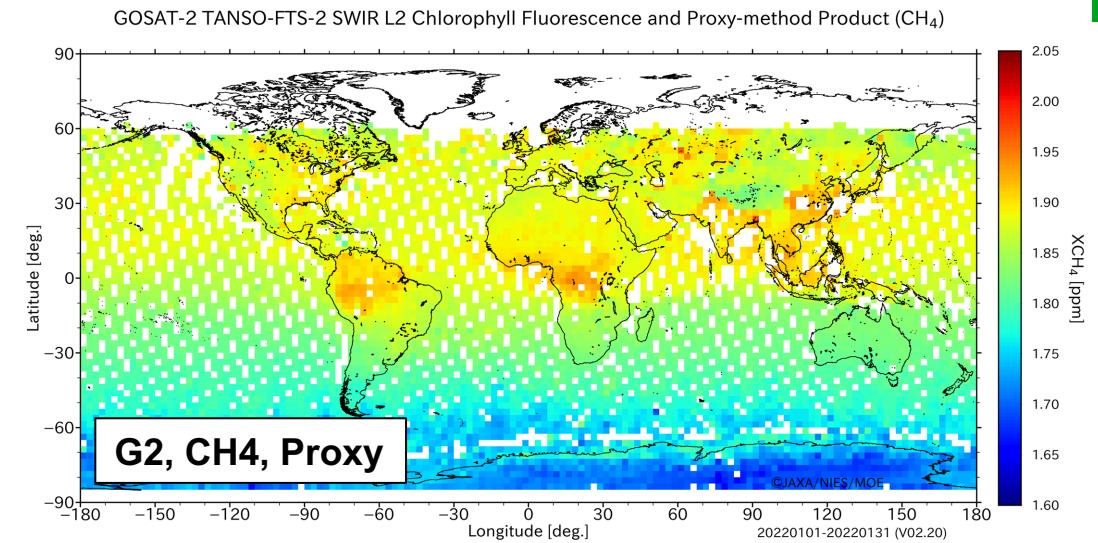
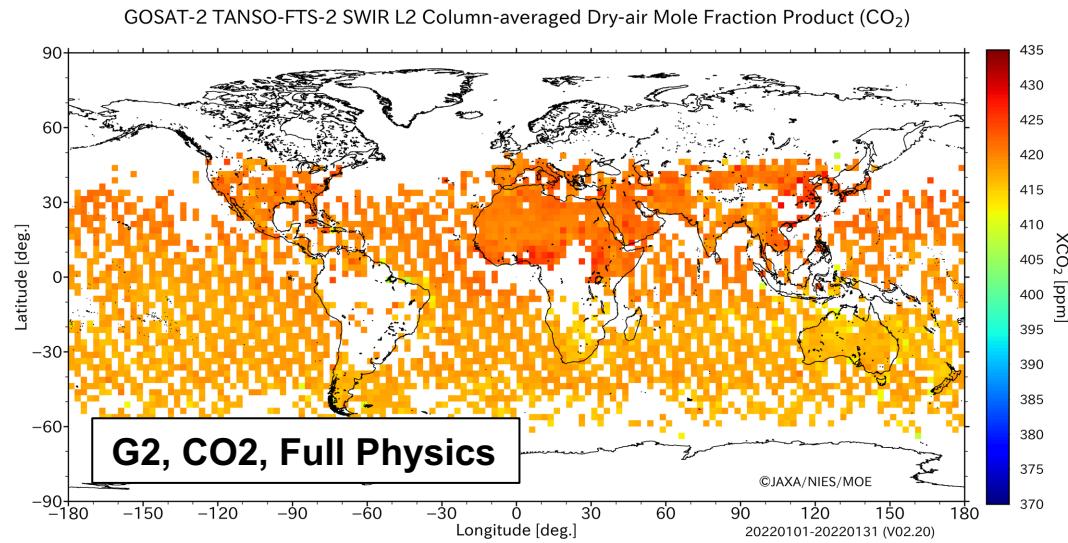
High spectral resolution spectrometers onboard GHG satellites observe the sunlight reflected at land/ocean surfaces or scattered by clouds and aerosols in the atmosphere with hundreds or thousands of spectral bands.

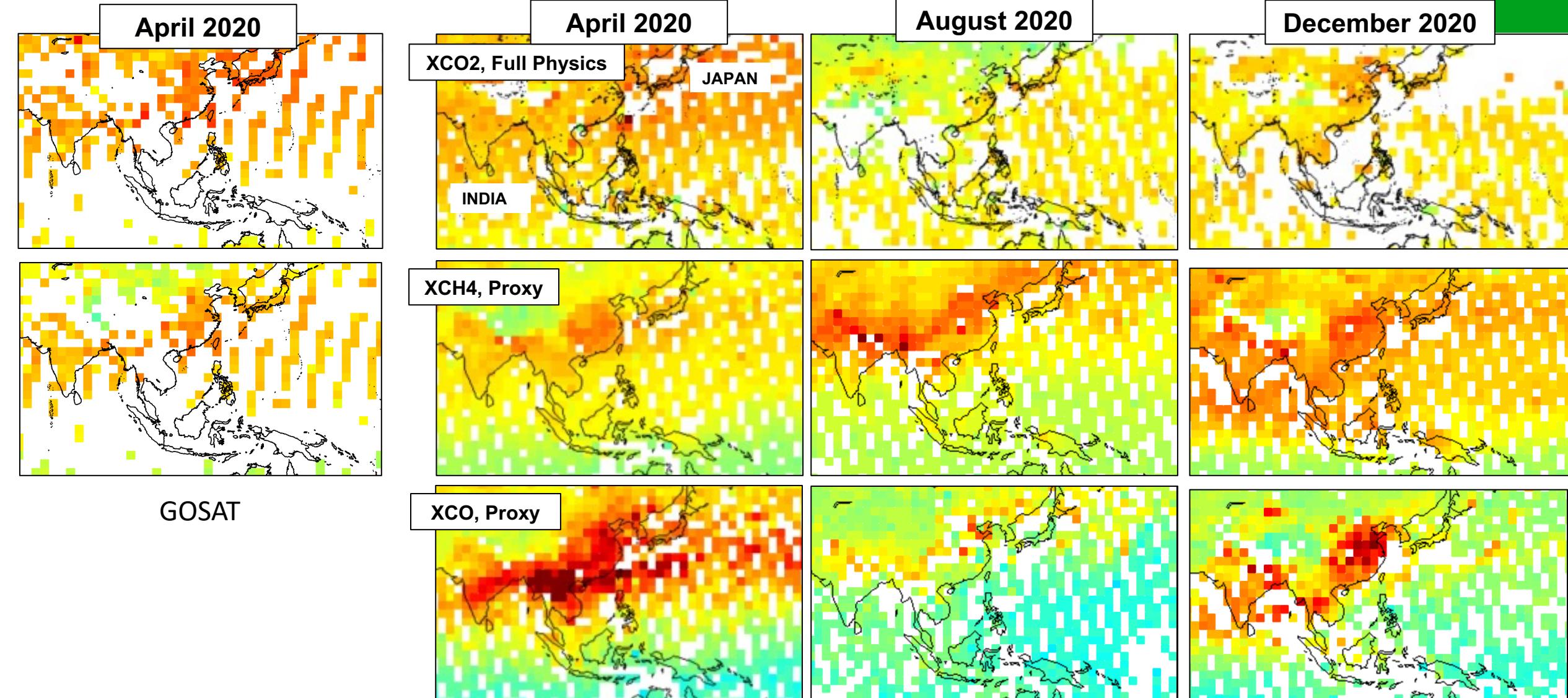


Vertical average concentrations of GHGs can be obtained from wavelengths and depths of absorption lines caused by molecules of GHGs and O₂ in 0.7, 1.6 and 2 μm regions.

GOSAT-2 XCO₂, XCH₄, and XCO monthly maps (V02.20, 2.5 × 2.5 deg): January 2022 to December 2023

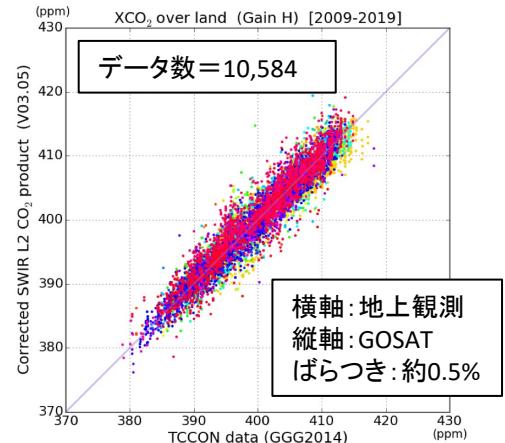
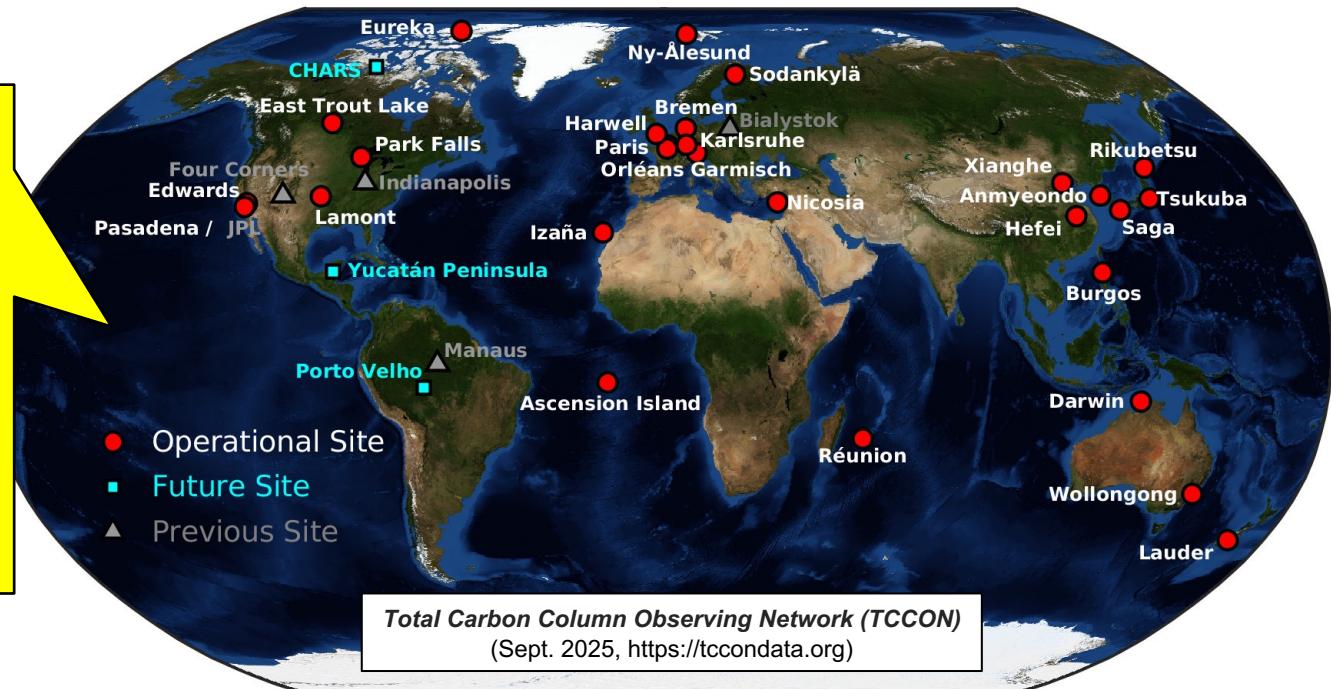
14



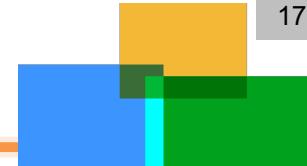


GOSATによる温室効果ガス濃度データの検証: 地上設置高分解能フーリエ変換分光計のネットワークの活用

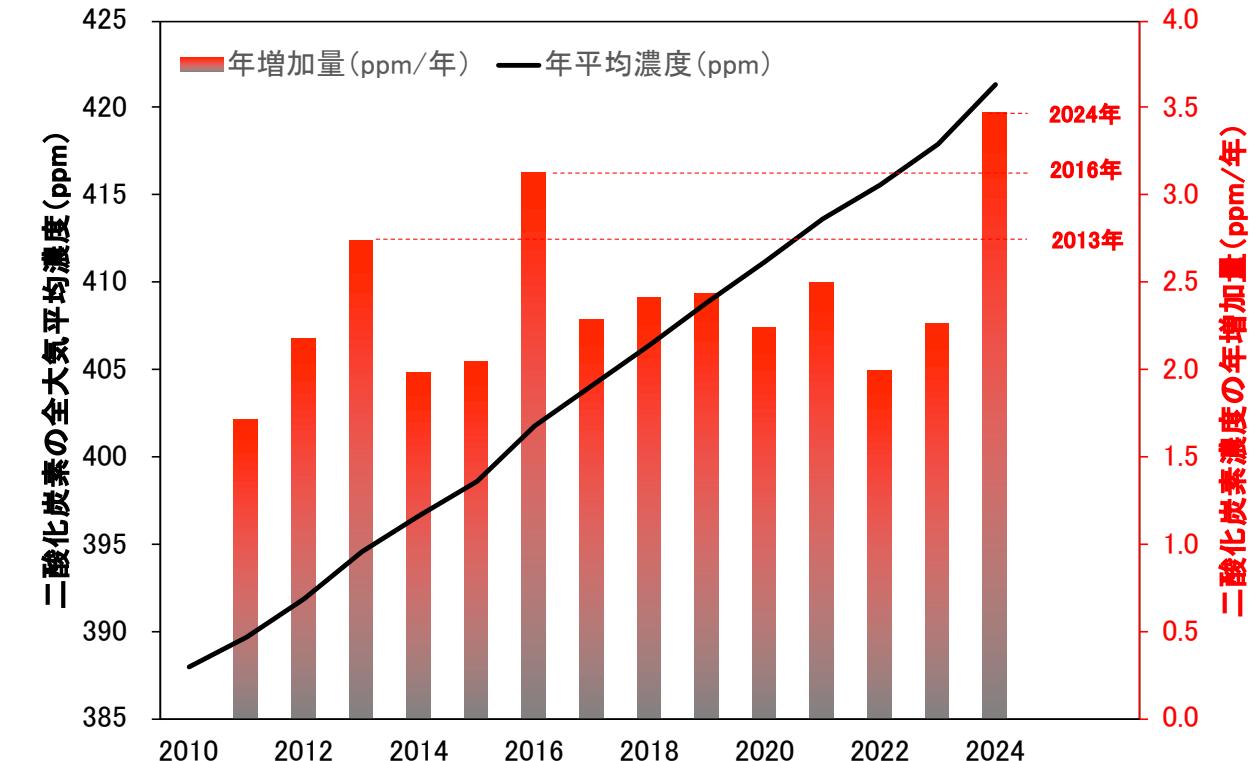
衛星と同時に地上から(より高精度の機器で)太陽光を観測した結果と比較し、衛星データの精度が0.5%程度であることを明らかにした。



GOSAT全大気平均濃度:過去14~15年間の年平均濃度と年増加量



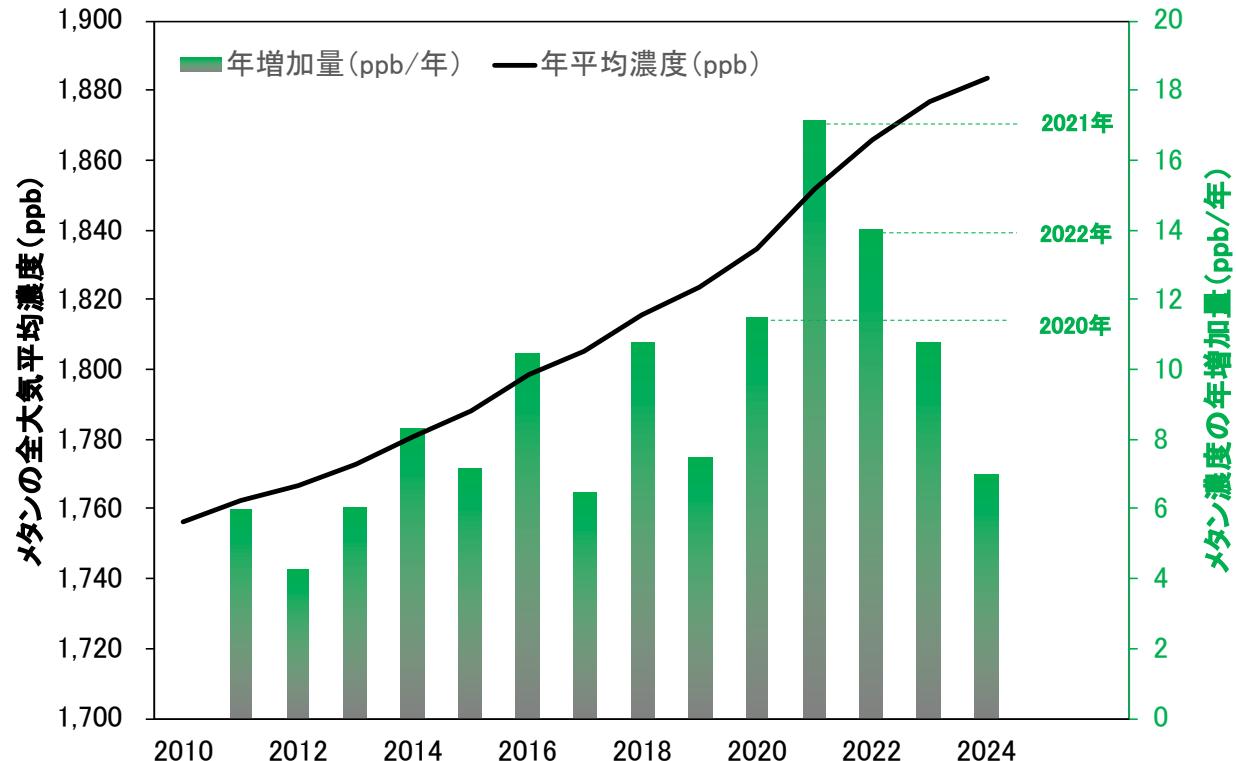
GOSATによる二酸化炭素の全大気平均濃度とその年増加量



地球全体の二酸化炭素濃度の年増加量が
過去14年間で最大に
～いぶき(GOSAT)による2024年の観測速報～

<https://www.nies.go.jp/whatsnew/2025/20250206/20250206.html>

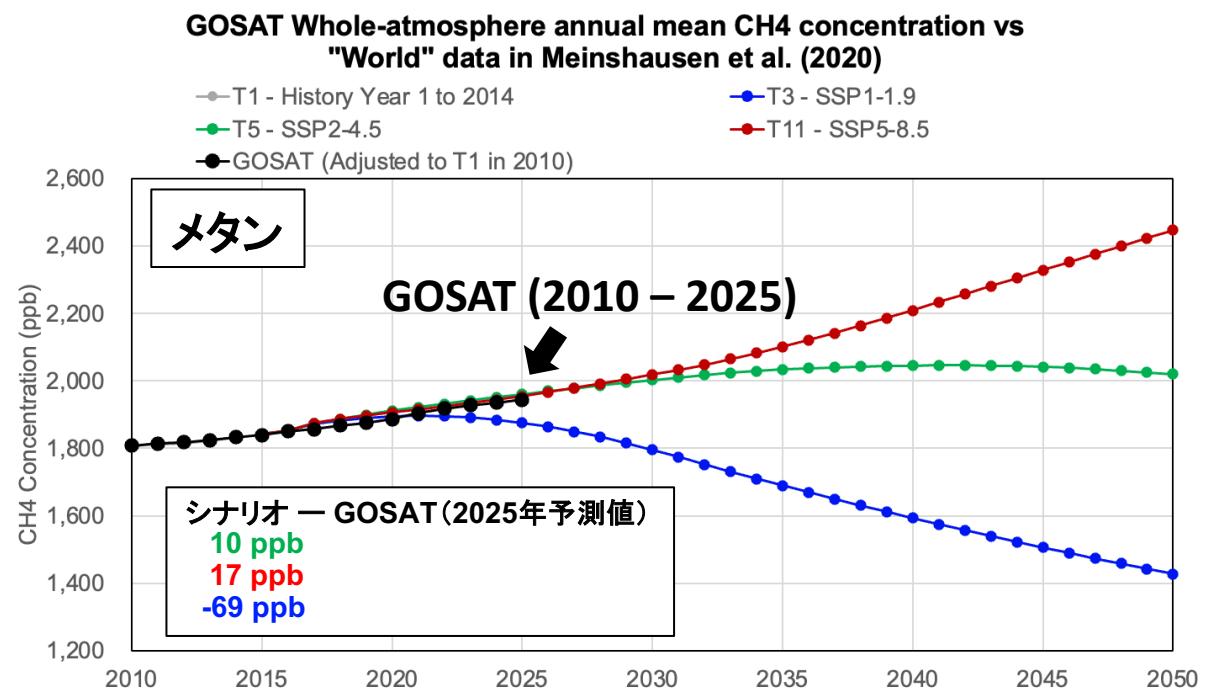
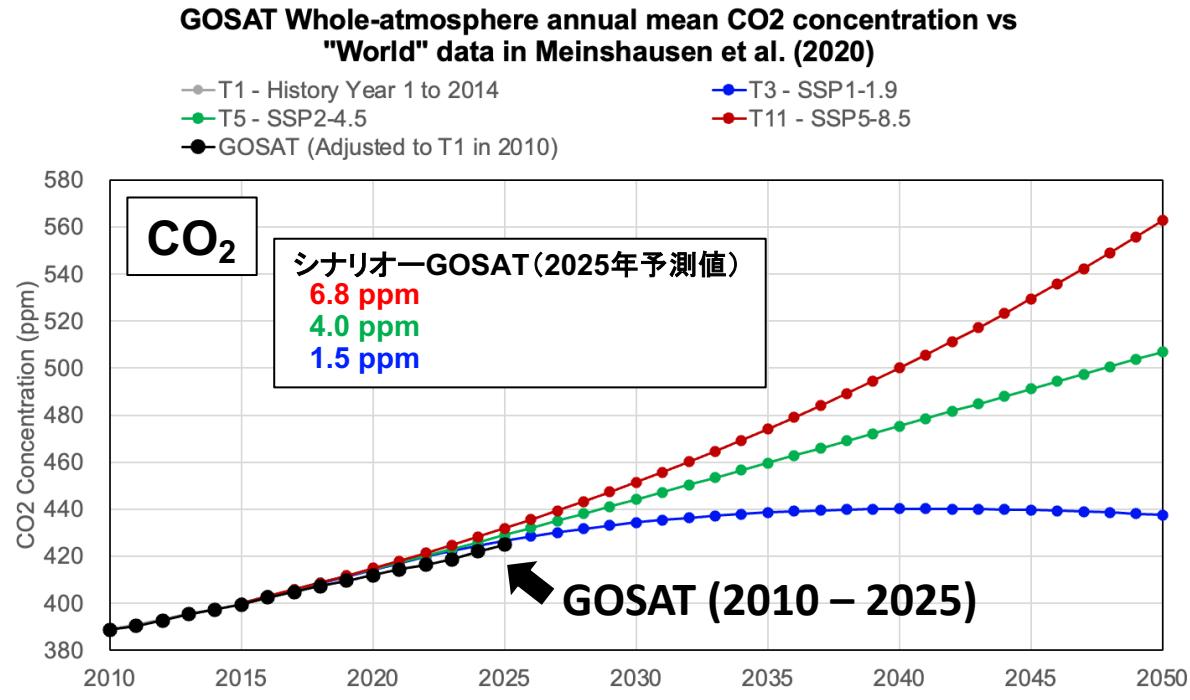
GOSATによるメタンの全大気平均濃度とその年増加量



メタンの全大気平均濃度の2021年の年増加量が
2011年以降で最大になりました
～GOSAT(「いぶき」)の観測データより～

<https://www.nies.go.jp/whatsnew/20220310/20220310.html>

GOSATによる全大気平均濃度(2010~2025年)と 共通社会経済経路(SSP、2015~2050年)における温室効果ガス濃度の比較



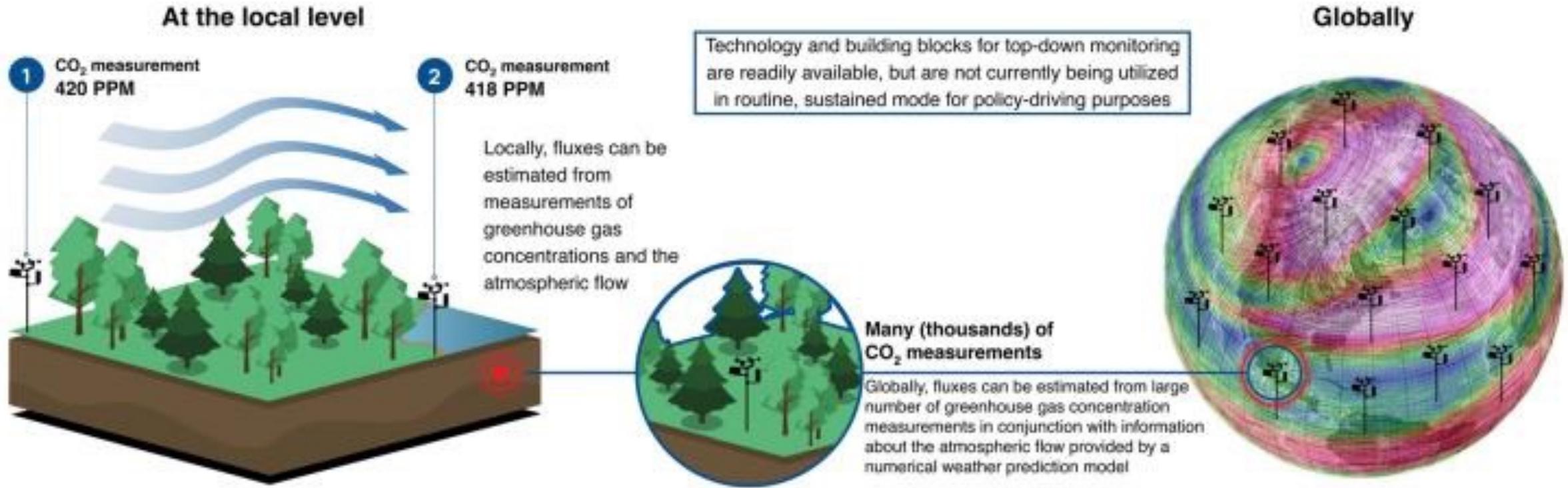
SSP シナリオと気温上昇の予測値

| シナリオ | 短期(2021~2040年) | | 中期(2041~2060年) | | 長期(2081~2100年) | |
|----------|----------------|-----------------|----------------|-----------------|----------------|-----------------|
| | 最良 推定値 | 可能性が非常に 高い範囲 | 最良 推定値 | 可能性が非常に 高い範囲 | 最良 推定値 | 可能性が非常 に高い範囲 |
| SSP5-8.5 | 1.6 °C | 1.3 – 1.9 °C | 2.4 °C | 1.9 – 3.0 °C | 4.4 °C | 3.3 – 5.7 °C |
| SSP2-4.5 | 1.5 °C | 1.2 – 1.8 °C | 2.0 °C | 1.6 – 2.5 °C | 2.7 °C | 2.1 – 3.5 °C |
| SSP1-1.9 | 1.5 °C | 1.2 – 1.7 °C | 1.6 °C | 1.2 – 2.0 °C | 1.4 °C | 1.0 – 1.8 °C |

GOSATシリーズによる全大気平均濃度により、実際の温室効果ガス濃度がどのシナリオに近いかを準リアルタイムに確認することができる。

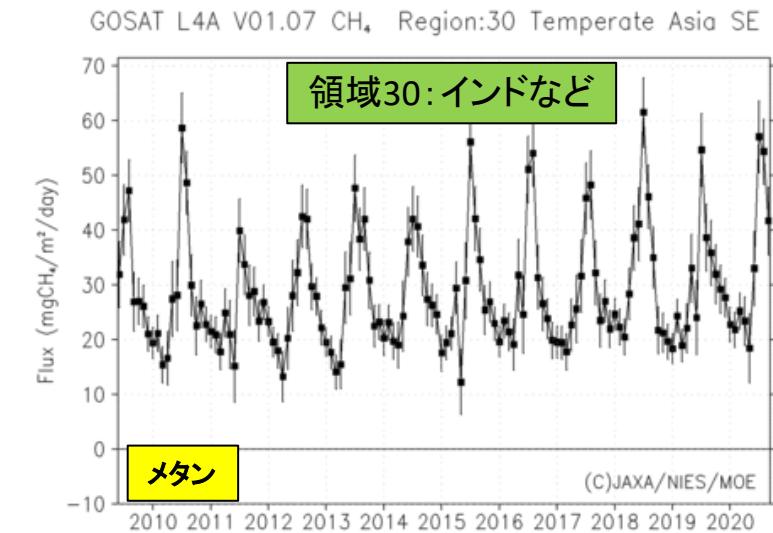
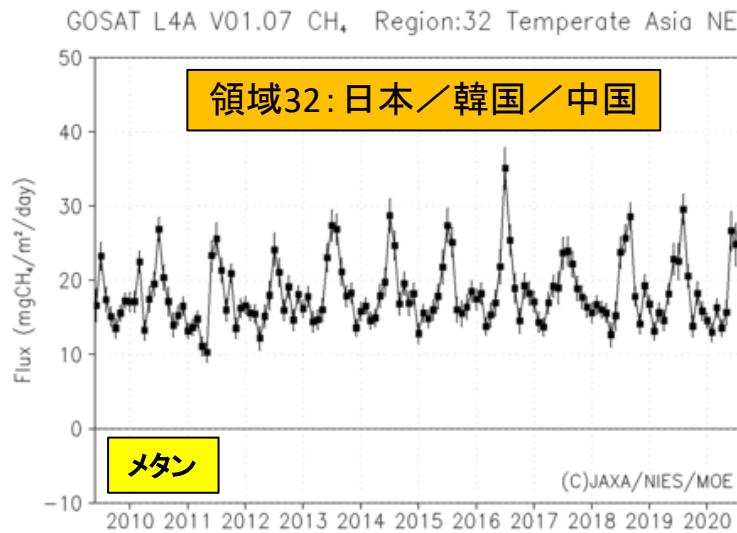
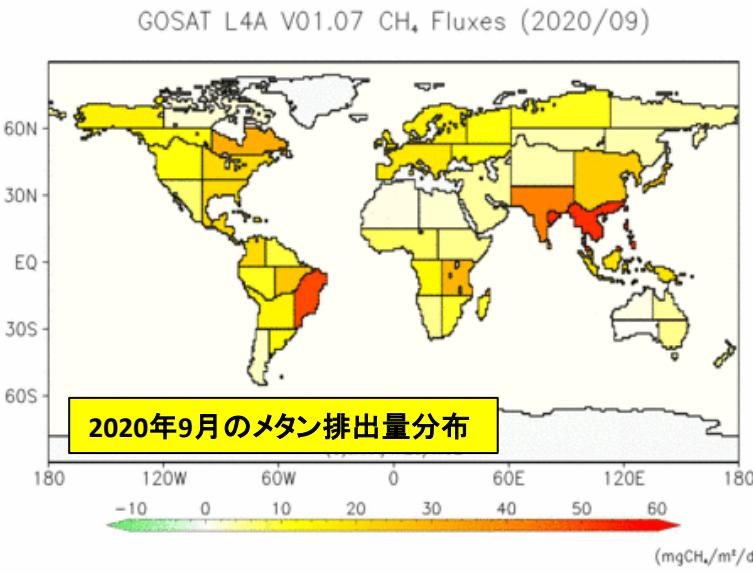
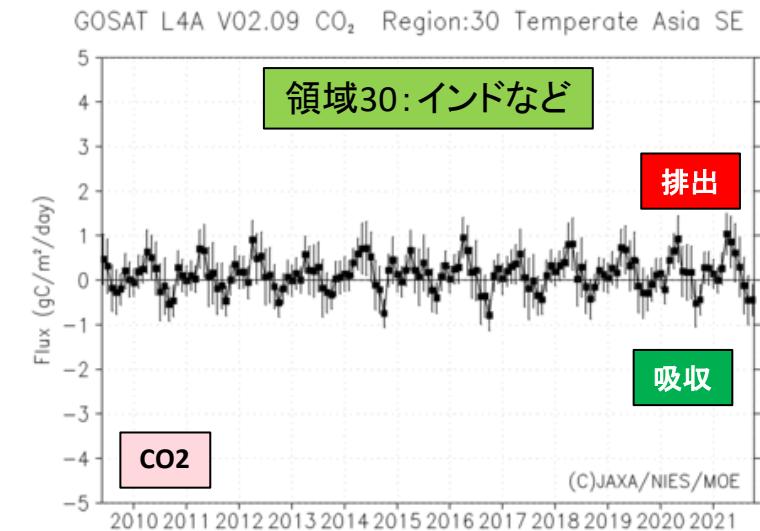
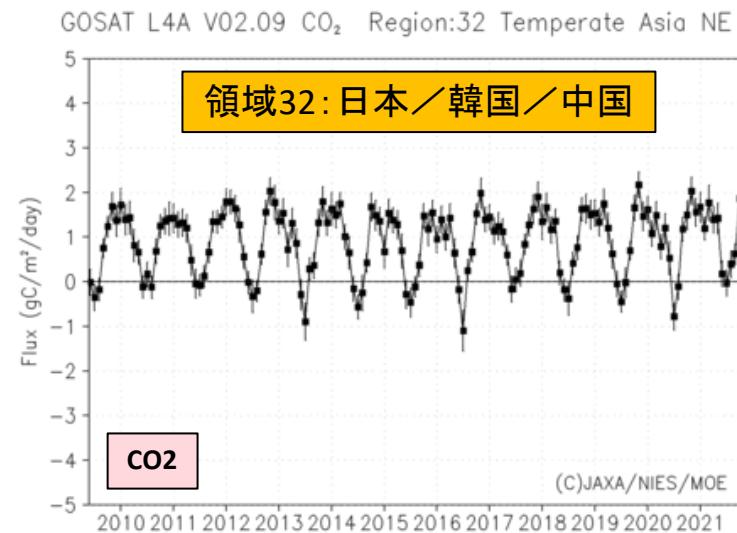
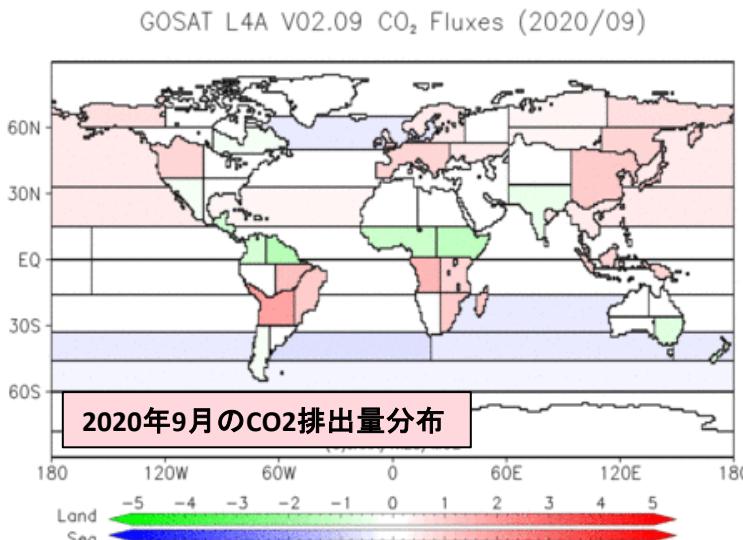
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf

How to estimate GHG fluxes from concentration data (Top-down approach)

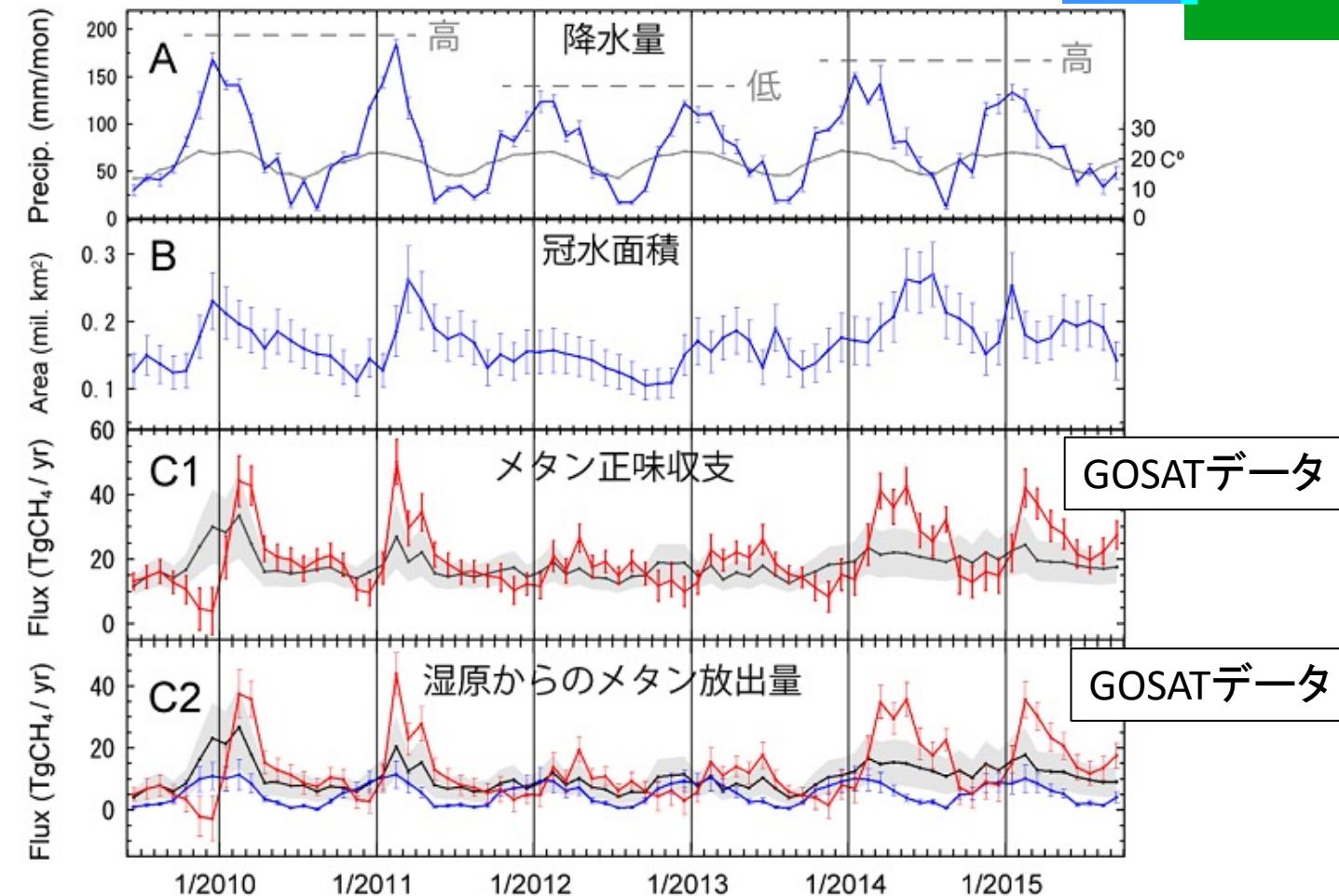
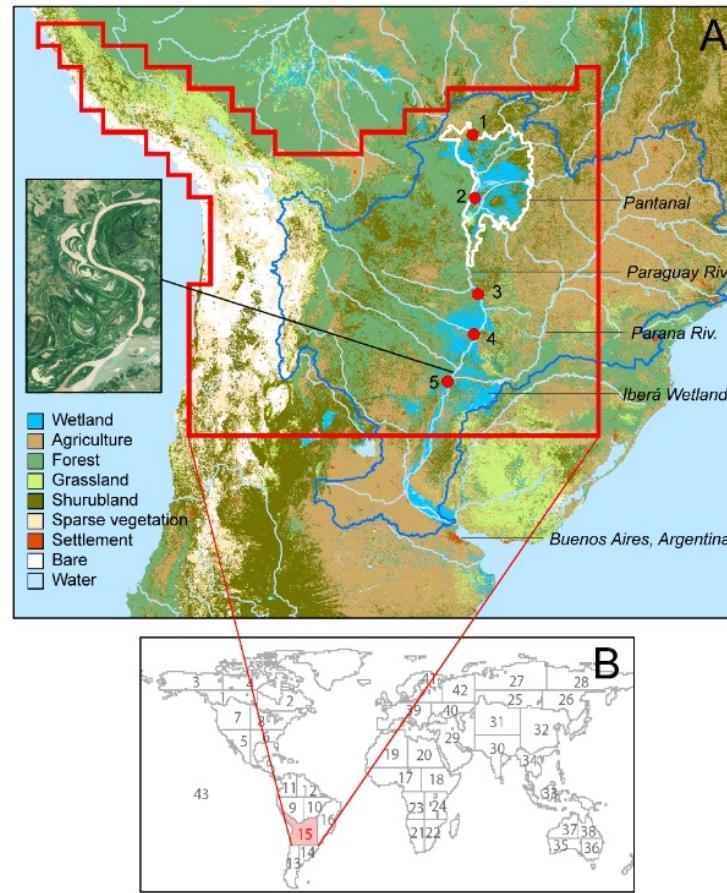


Top-down approach combines observations of atmospheric greenhouse gas concentrations with atmospheric modelling to estimate net fluxes.
 Prior flux data are modified (optimized) to better fit observed concentration data.
 Satellite GHG concentration data are being used in this process.

二酸化炭素、メタンの吸収排出量分布の推定について (GOSATレベル4Aプロダクト)



南米中部のメタン排出量と降水量等との関係(Takagi et al., SOLA, 2021)



- GOSATレベル4Aプロダクトを用いて、南米亜熱帯域の2009～2015年のメタン排出量を解析した。
- 湿地の多い同領域のメタン排出量は陸水貯留量、湿地面積、降水量などとの相関が高い。
- 南米亜熱帯域は将来の気候変動により降水量(→メタン排出量)が変動する可能性がある。

2016 – 2022 Methane Inversion Using Surface, Airborne, and GOSAT Data (Niwa et al., ACP, 2025)

22

(c) GOSAT

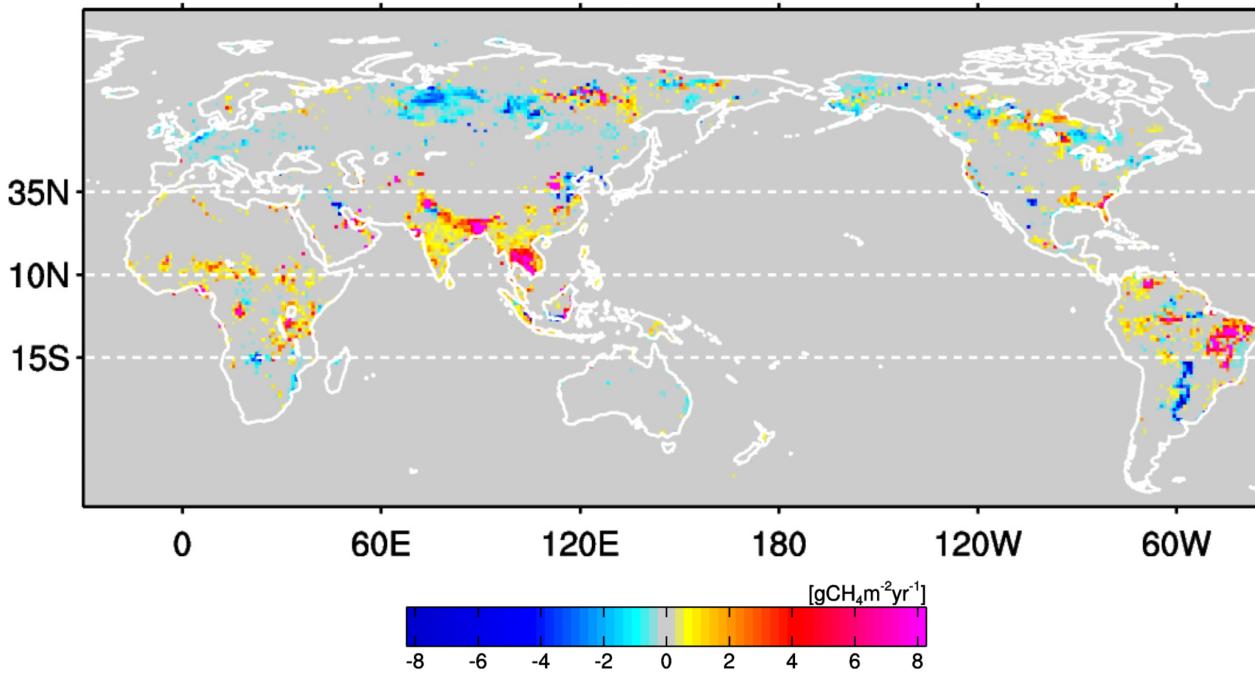


Figure 4c Spatial patterns of the total net CH_4 emissions increase ($\Delta f\text{CH}_4$) from 2016–2019 to 2020–2022 in the GOSAT inversion.

The increase of emissions from Wetland in Tropics and Agriculture / Waste in North Low-latitude made a significant contribution to 2021 methane surge.

<https://acp.copernicus.org/articles/25/6757/2025/>

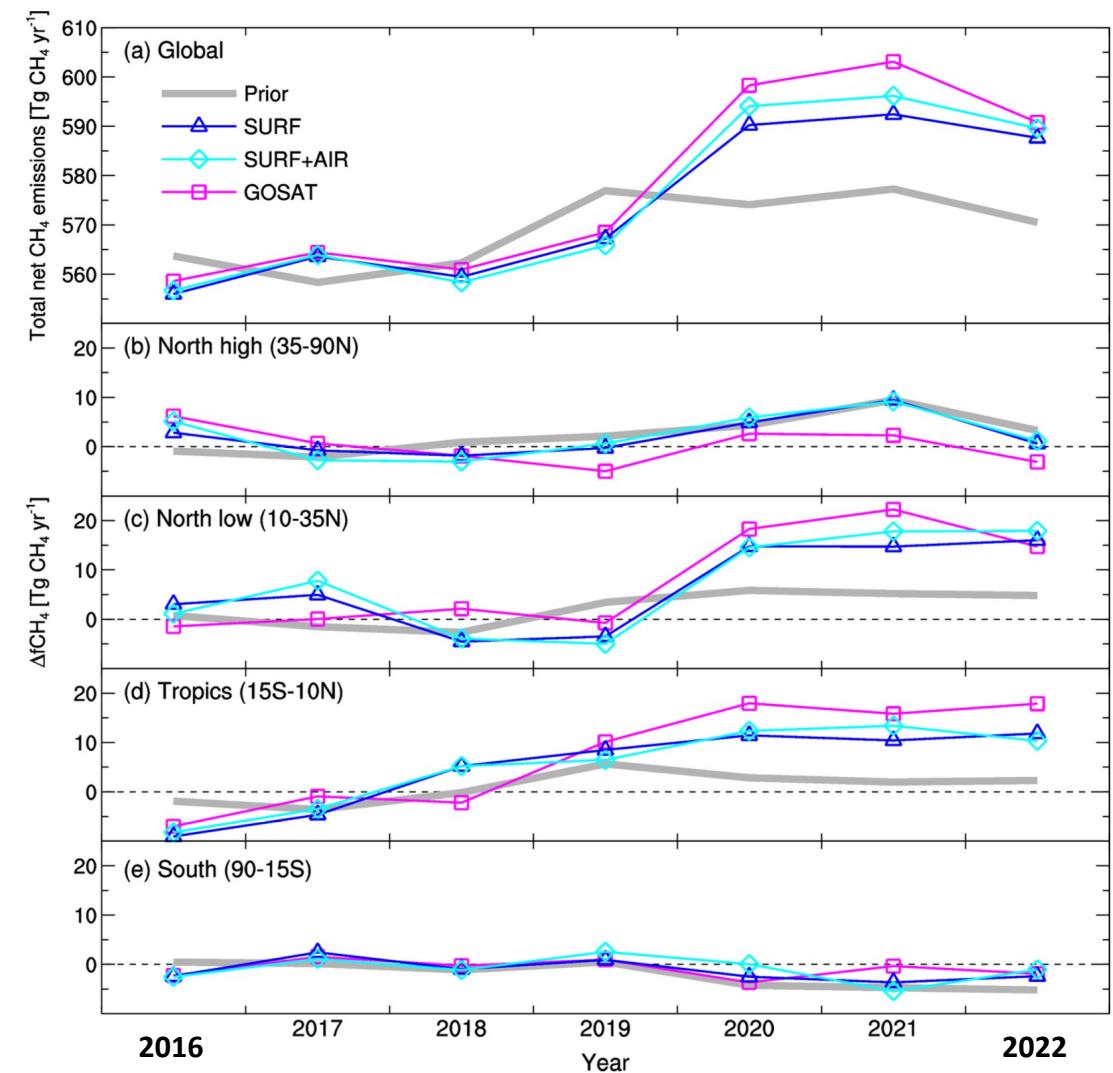
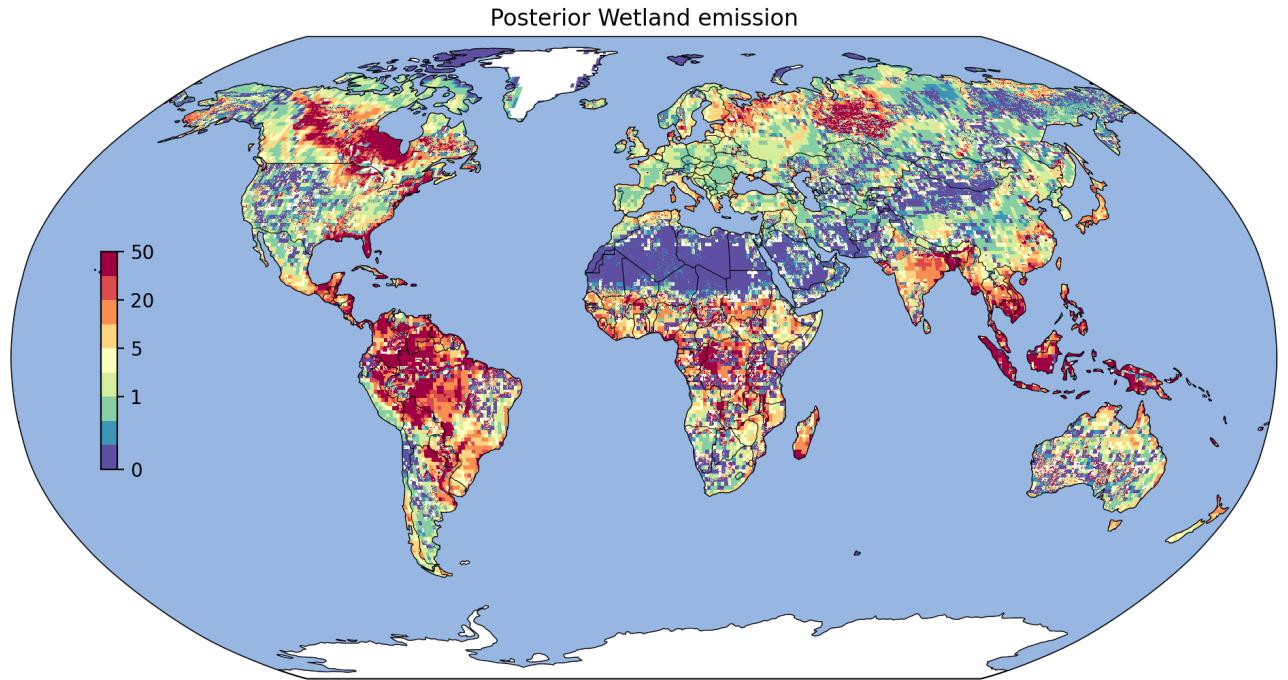
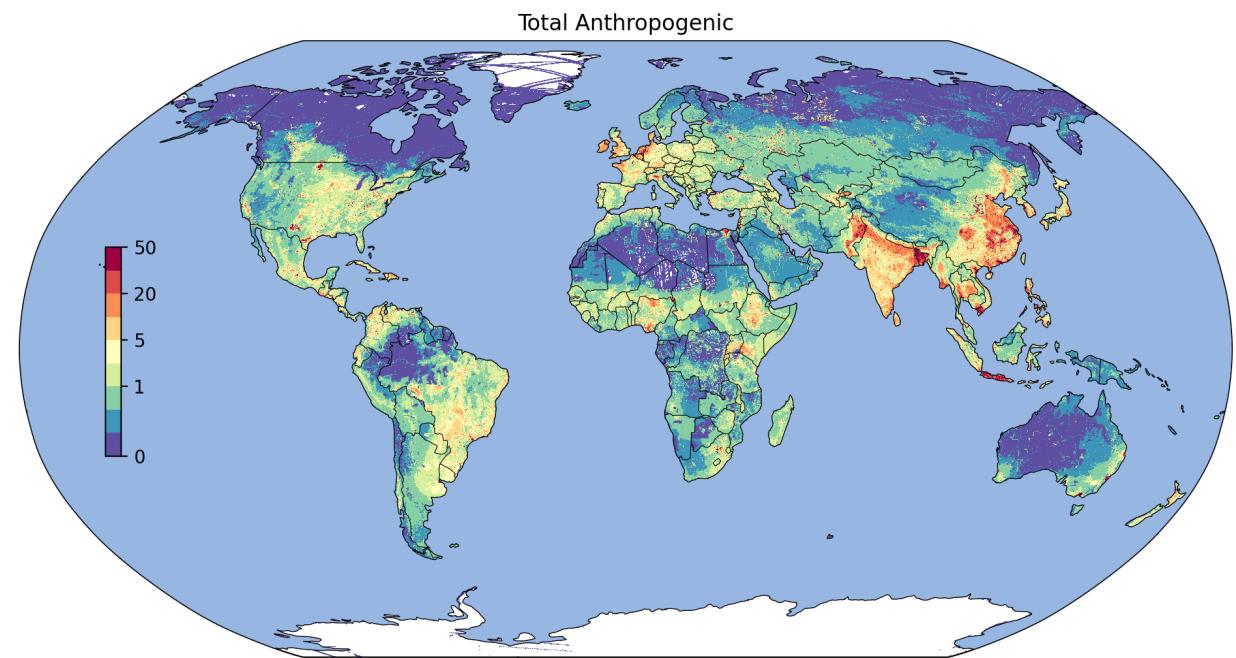


Figure 5 Year-to-year variations of total net CH_4 emissions

2009 – 2022 Anthropogenic and Wetland Methane Emission Maps Derived from NTFVAR Inversion Using GOSAT Data



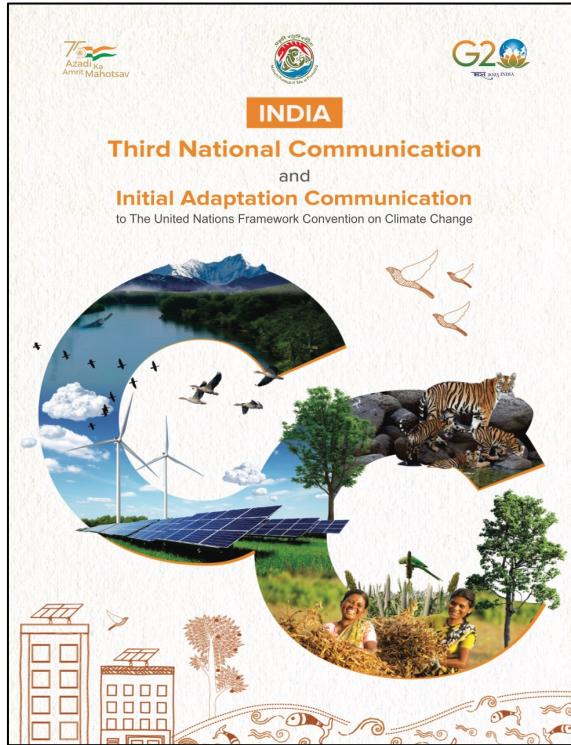
Janardanan et al. (2025)のGOSATデータを用いた
NTFVARインバージョンに基づく
2009～2022年の人為起源CH₄排出量 (gCH₄/m²/yr)
人為起源=石油・天然ガス+石炭+農業
+廃棄物+バイオマス燃焼

Janardanan et al. (2025)のGOSATデータを用いた
NTFVARインバージョンに基づく
2009～2022年の自然湿地起源CH₄排出量 (gCH₄/m²/yr)

インドの第3回国別報告書(2023年11月)におけるGOSATに関する記載

5.11 Estimation of CH₄ Fluxes During 2011-2017 Using Top-down Modeling and Observations

<https://unfccc.int/documents/636235>



「2011-2017年の国全体のメタン排出量についてGOSATデータを使ったトップダウンのモデル解析(インバージョン)が行われている(Janardanan et al., 2020)。」

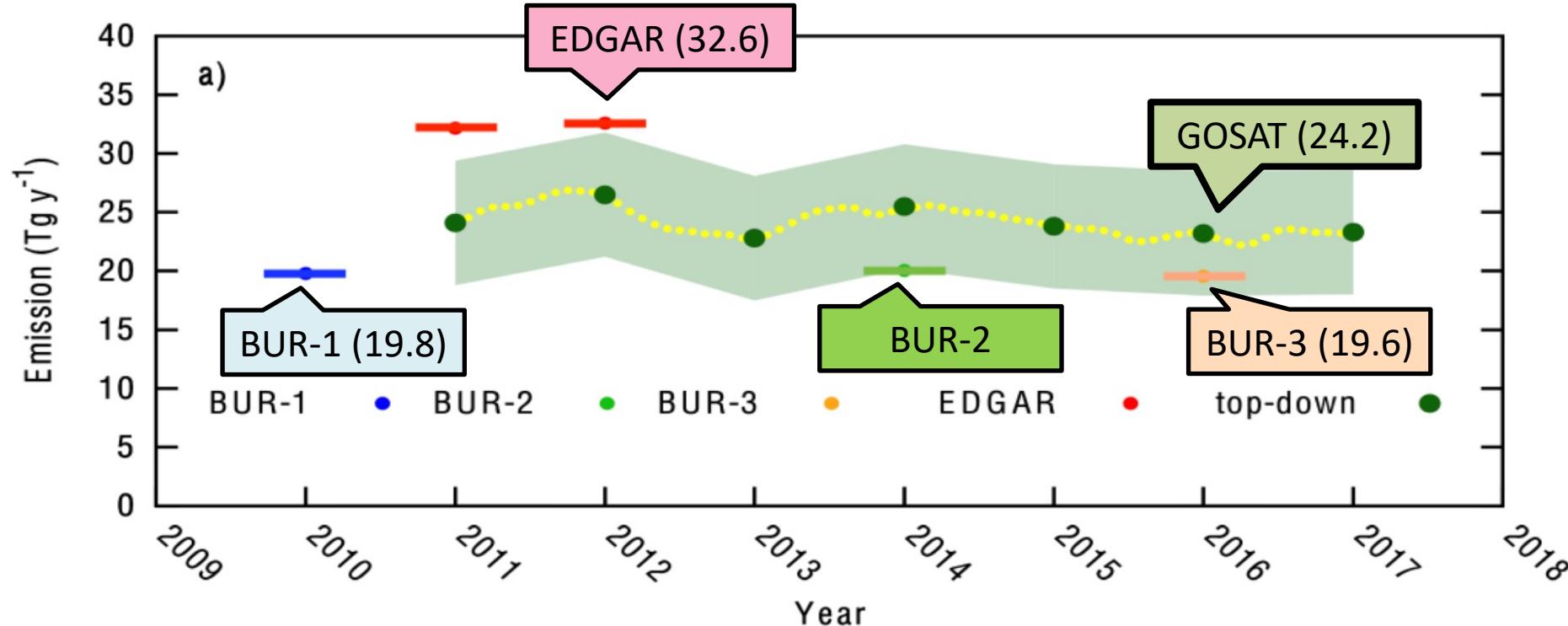
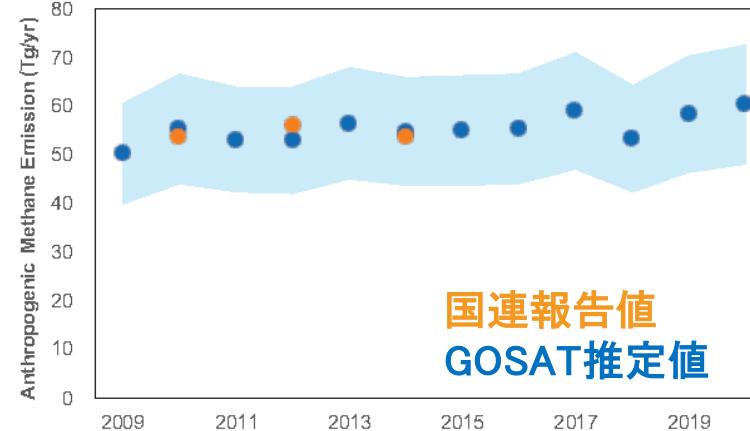


Figure 5.17: トップダウン法によるインドの人為起源メタン排出の推定値量(GOSAT、2011-2017年)。隔年更新報告書(BUR-1、2、3)や欧州のデータベース(EDGAR)の数値も併記。

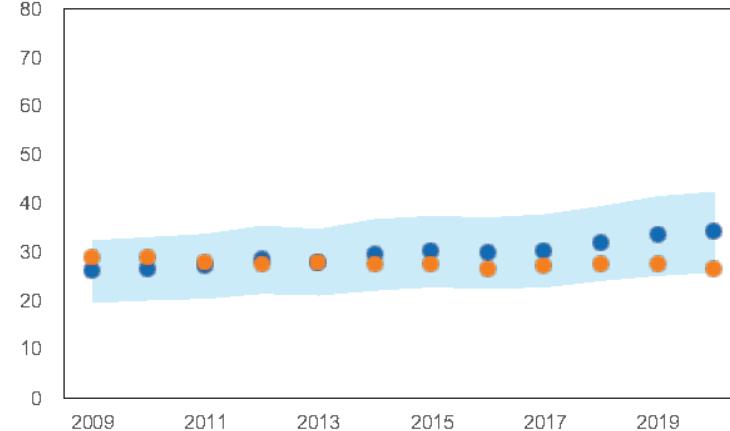
GOSATシリーズデータはインバース解析による温室効果ガス排出量の推定や各国の排出インベントリの評価に使われている。

GOSATで世界各国の人為起源排出インベントリを検証する – メタン (2009–2020)

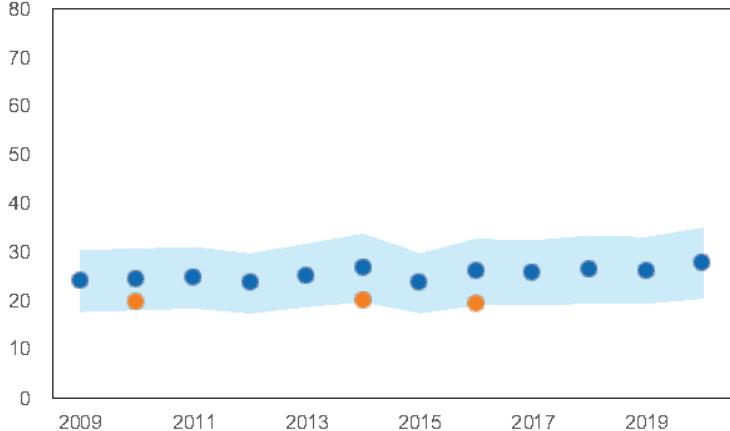
中国



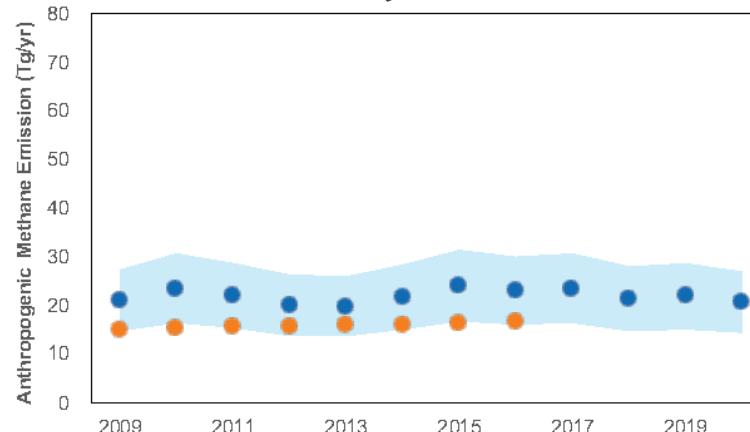
米国



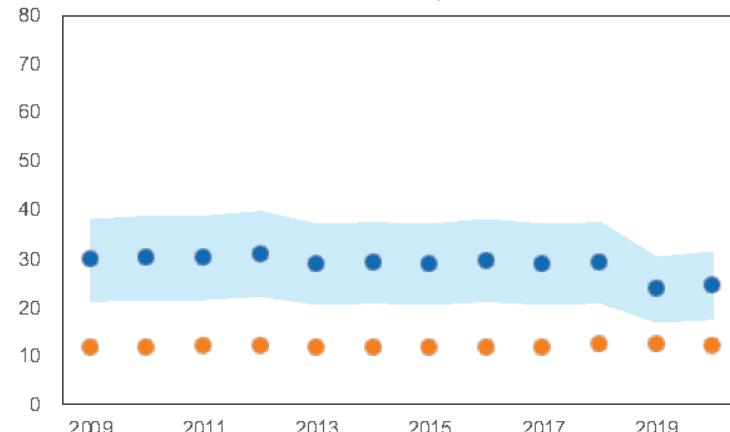
インド



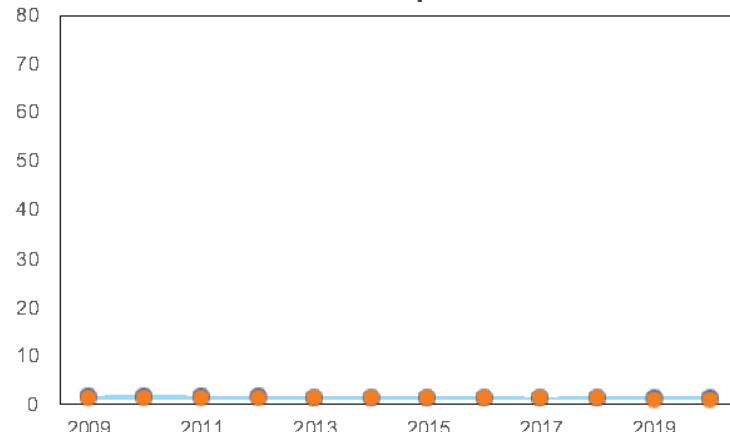
ブラジル



ロシア



日本



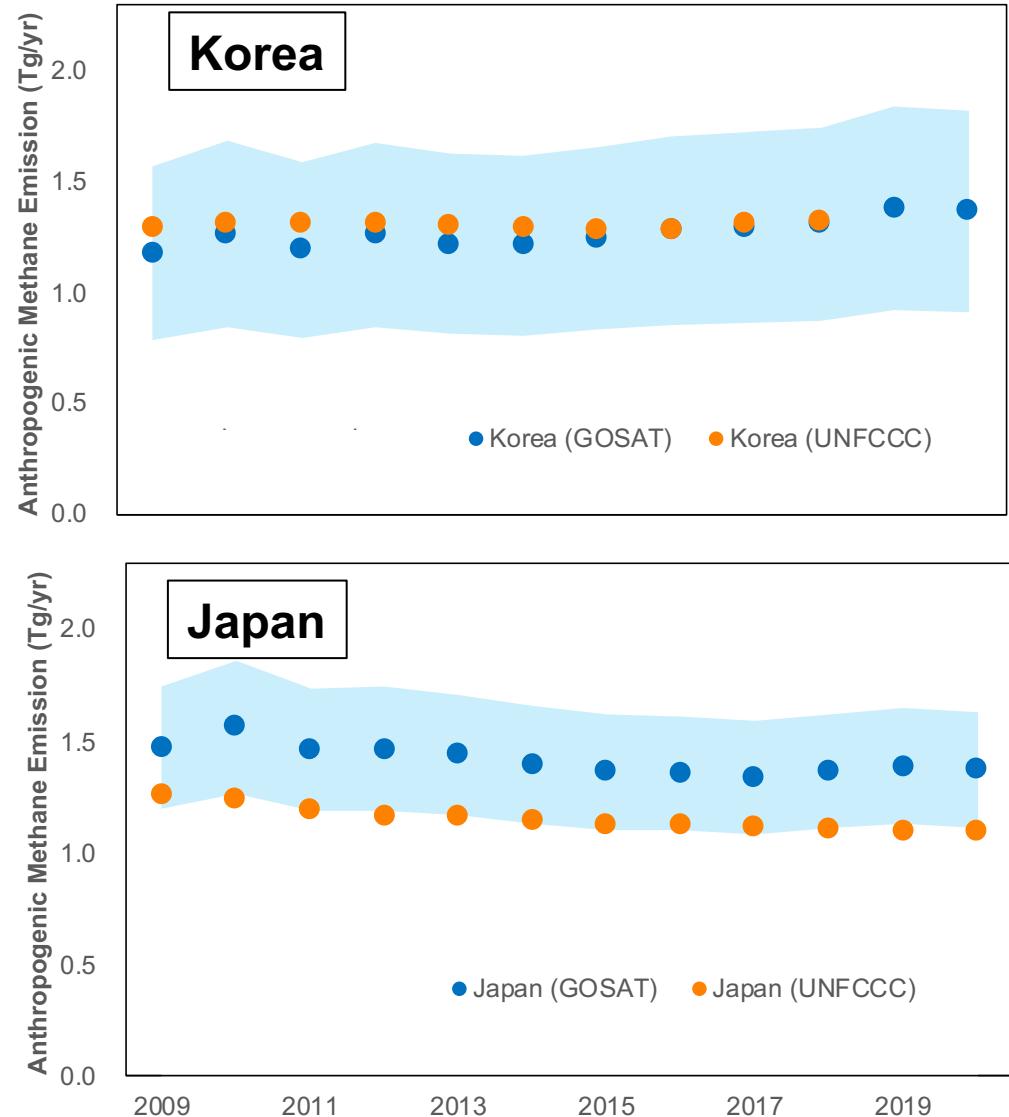
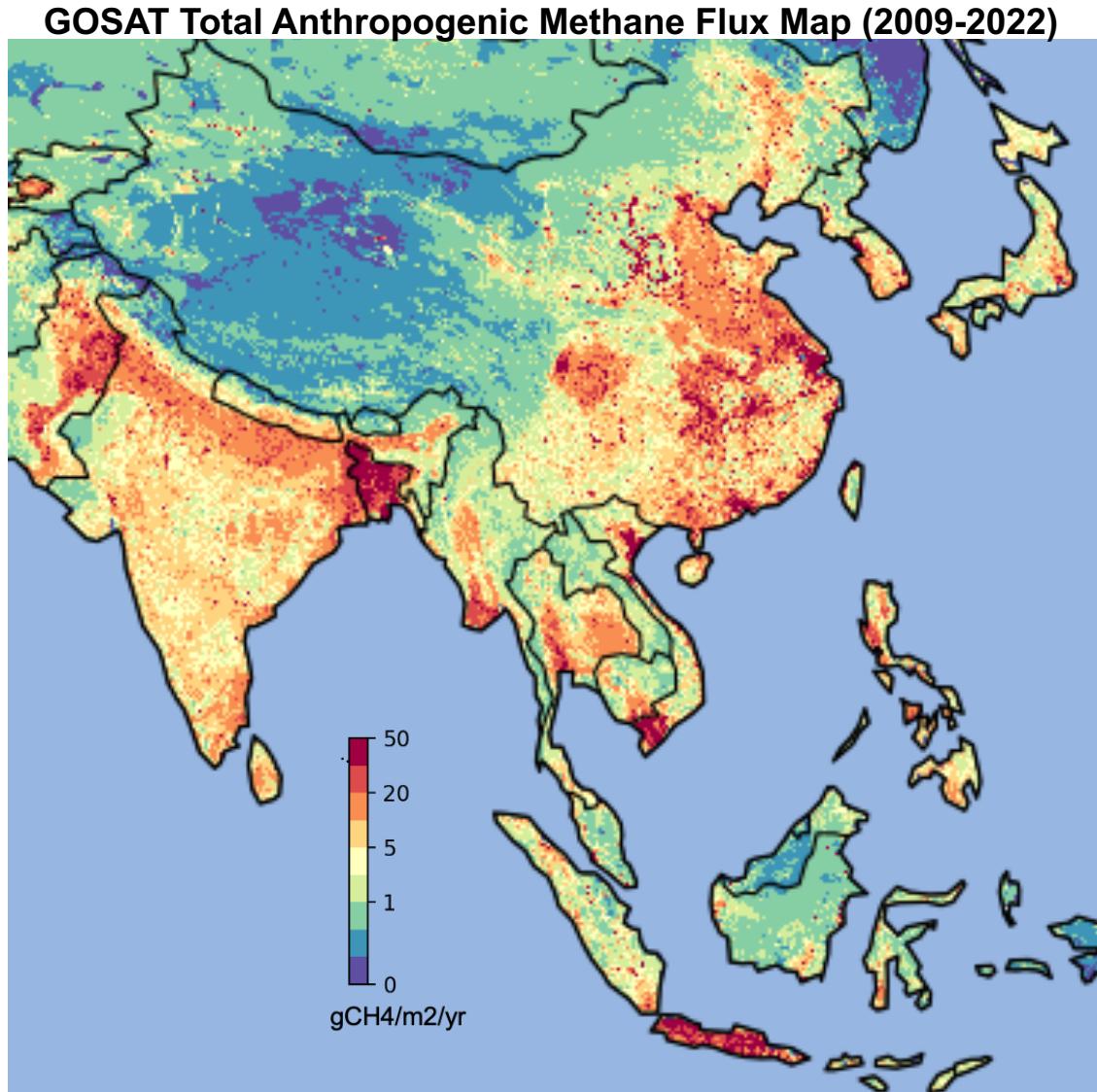
Anthropogenic methane fluxes from inversion analyses of GOSAT data (Janardanan et al. 2024) and UNFCCC Data

<https://esd.nies.go.jp/ghg-information/>

2009 – 2020 Anthropogenic Methane Emissions (Korea and Japan)

Derived from GOSAT Data (Janardanan et al., 2024)

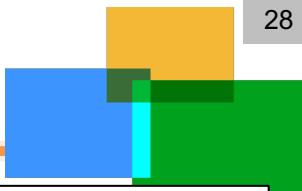
26



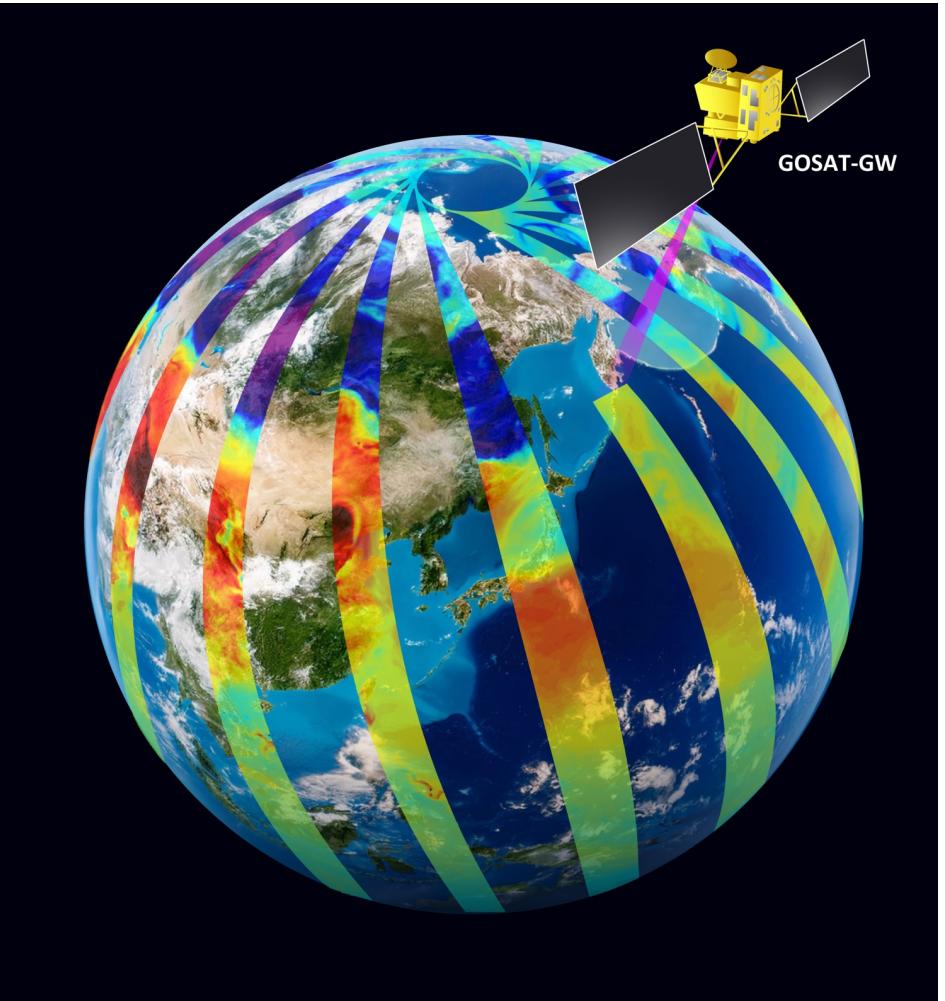
The third satellite in GOSAT Series



GOSAT-GWに搭載されたTANSO-3による温室効果ガス観測について: 広域観測モードと精密観測モード



TANSO-3広域観測モード



TANSO-3精密観測モード



観測範囲: 90 x 90 km

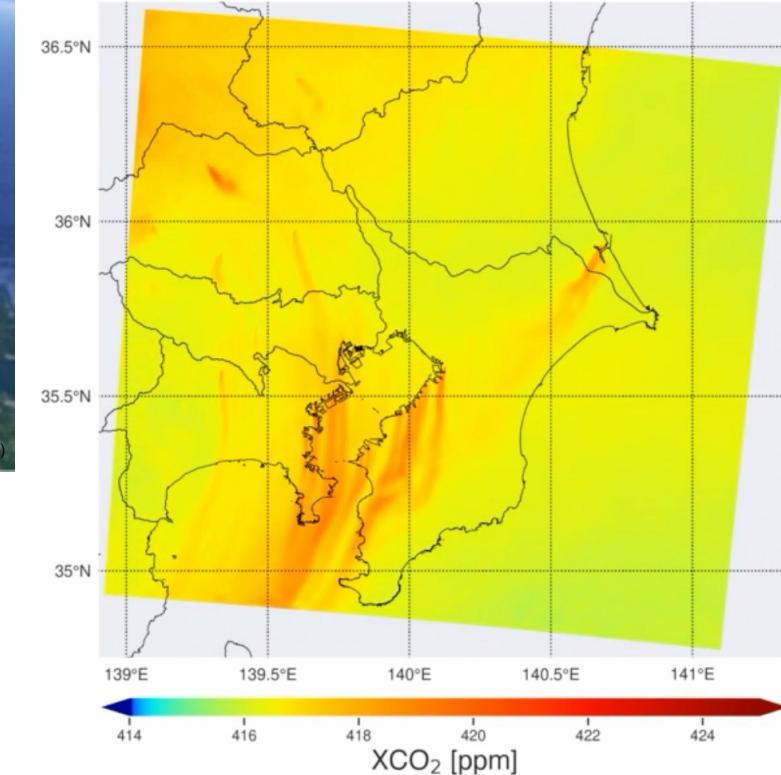
空間分解能: 1 – 3 km

観測領域数: 3日間で約90領域

精密観測モードによる観測は内外のユーザからの観測要求に基づいた観測計画に従つて計画的に実施されます。

観測されたデータは無償で一般公開されます。

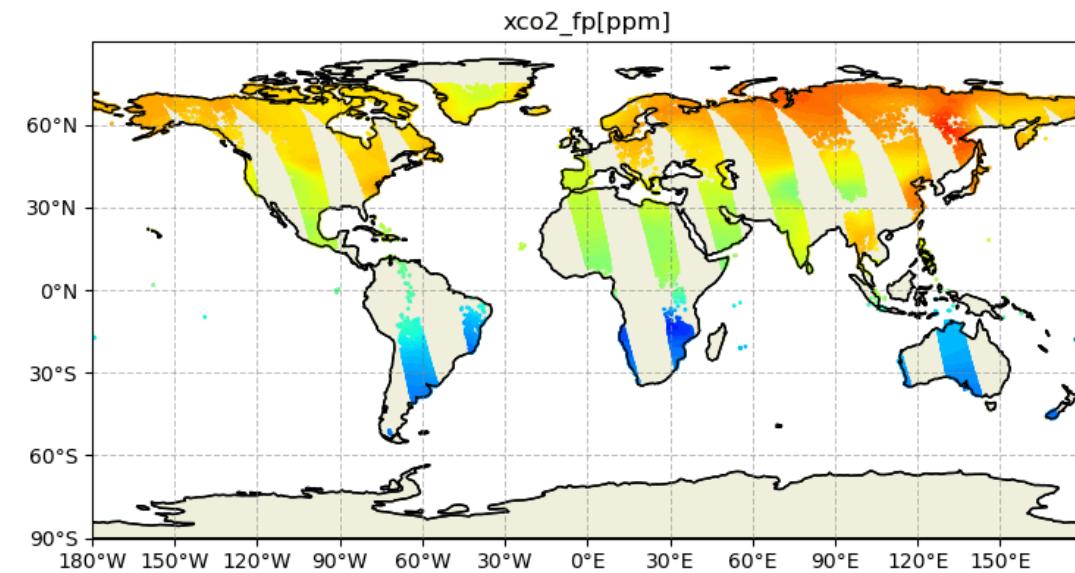
TANSO-3による東京周辺の
CO₂観測(シミュレーション)



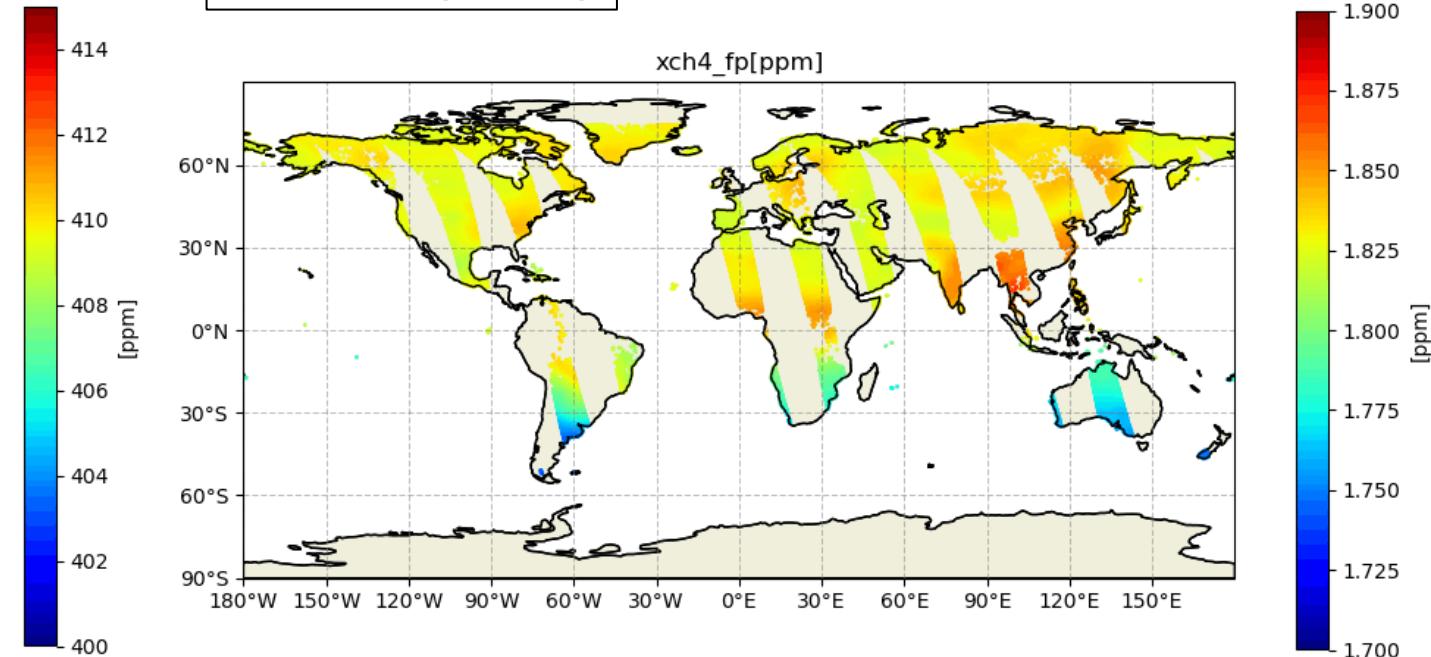
JAMSTEC金谷氏提供
山口ほか(2024)日本リモートセンシング学会誌

Simulated GOSAT-GW TANSO-3 L2 GHG Product (Wide Mode)

Carbon Dioxide (XCO₂)



Methane (XCH₄)



GOSAT-GW TANSO-3 covers the entire globe every three days.

GHG data source:
Cloud data source:
Animation time step:

GOSAT L4B Concentration products (April – June 2018)
GEWEX Cloud Assessment
One day (= one L2 product = 14 – 15 path/day)

Thank you for your attention

Website

<https://www.nies.go.jp/soc> (NIES Satellite Observation Center)

<https://www.gosat.nies.go.jp> (NIES GOSAT Project)

<https://www.gosat-2.nies.go.jp> (NIES GOSAT-2 Project)

<https://gosat-gw.nies.go.jp> (NIES GOSAT-GW Project)

GOSAT and GOSAT-2 standard products are freely available from

GOSAT Data Archive Service (GDAS: L1B, L2, L3, L4)

<https://data2.gosat.nies.go.jp>

GOSAT-2 Product Archive (L1B, L2, L4)

<https://prdct.gosat-2.nies.go.jp>

Tellus (GOSAT L2, L3, L4 and GOSAT-2 L2, L4)

<https://www.tellusxdp.com/en-us/>

GOSAT-GW TANSO-3 standard products will be freely available from

GOSAT-GW TANSO-3 Product Archive (G3PA: L1B, L2)

<https://product.gosat-gw.nies.go.jp/>