Monitoring greenhouse gas emissions from the CubeSats: Algorithm development plans

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Abstract

Although the total amount of methane (CH_4) is significantly lower than that of carbon dioxide (CO_2), methane is known to accelerate global warming due to its high Global Warming Potential (GWP) and recent increasing trends. As countries around the world prepare for the era of carbon neutrality, they are competitively developing systems to take a leading role in calculating emissions. While ground-based observation equipment currently provides relatively accurate data, there are limitations in quantifying greenhouse gases from various sources. These limitations are particularly evident in marine areas and regions with insufficient ground-based observation data. To overcome these challenges, this study aims to develop a CubeSat for greenhouse gas monitoring. We plan to launch the first CubeSat in 2027, followed by the launch of four additional satellites in 2028. However, CubeSats may have lower observational accuracy compared to medium and large-scale satellites, making it crucial to develop algorithms that meet data quality and user requirements. Therefore, this study focuses on developing an algorithm that optimally retrieves methane concentrations. Once developed, this greenhouse gas monitoring algorithm will serve as a foundation for more accurate assessments of emission management policies, climate change prediction resources, and both short- and long-term trends in carbon dioxide and methane emissions.

Prior Research

- **Study Period - 2024. 04. 24 – 2024. 12. 23**
- **CubeSat Specification**

CubeSat Specifications		GHGSat	GEI-SAT	TANGO	MicroCarb
Spectrometer type		Fabry-Perot interferometer	Filter-based imager	Grating	Echelle grating
Band 1	Spectral Resolution Sampling Resolution FWHM SNR	1630-1675 nm 0.0001-0.1 nm 0.1 nm 200 8bit grey-scale imager	(iSIM-90) 450-1700 nm - -	405-490 nm × 2.3 oversampling 0.6 nm >300	764±10 nm (O_2) >2.8 oversampling $\lambda/\Delta\lambda \geq$ 25,000 480
Band 2	Spectral Resolution Sampling Resolution FWHM SNR		(Isim-170) -2300 nm - -	1590-1675 nm × 3.0 oversampling 0.455 nm 355	1608±17 nm (CO_2) >2.8 oversampling $\lambda/\Delta\lambda \geq$ 25,000 680
Band 3	Spectral Resolution Sampling Resolution FWHM SNR		-	-	2037±22 nm (CO_2) >2.8 oversampling $\lambda/\Delta\lambda \geq$ 25,000 325
Band 4	Spectral Resolution Sampling Resolution FWHM SNR		-	-	1273±27 nm (O_2) >2.8 oversampling $\lambda/\Delta\lambda \geq$ 25,000 670
Spatial Specifications		25 × 25 m^2 (GHGSat-CX) 50 × 50 m^2 (GHGSat-D)	1.65 m (VNIR) 13 m (SWIR)	300 × 300 m^2	3 IFOVs: 4.5 km (cross-track) x 9 km (along-track)
Retrieval accuracy		GHGSat-D: 13% (~230 ppb) GHGSat-CX: 1% (~18 ppb) of background CH_4			CO_2 Bias < 0.1 ppm Random noise < 1 ppm

- **TROPOMI yearly mean**

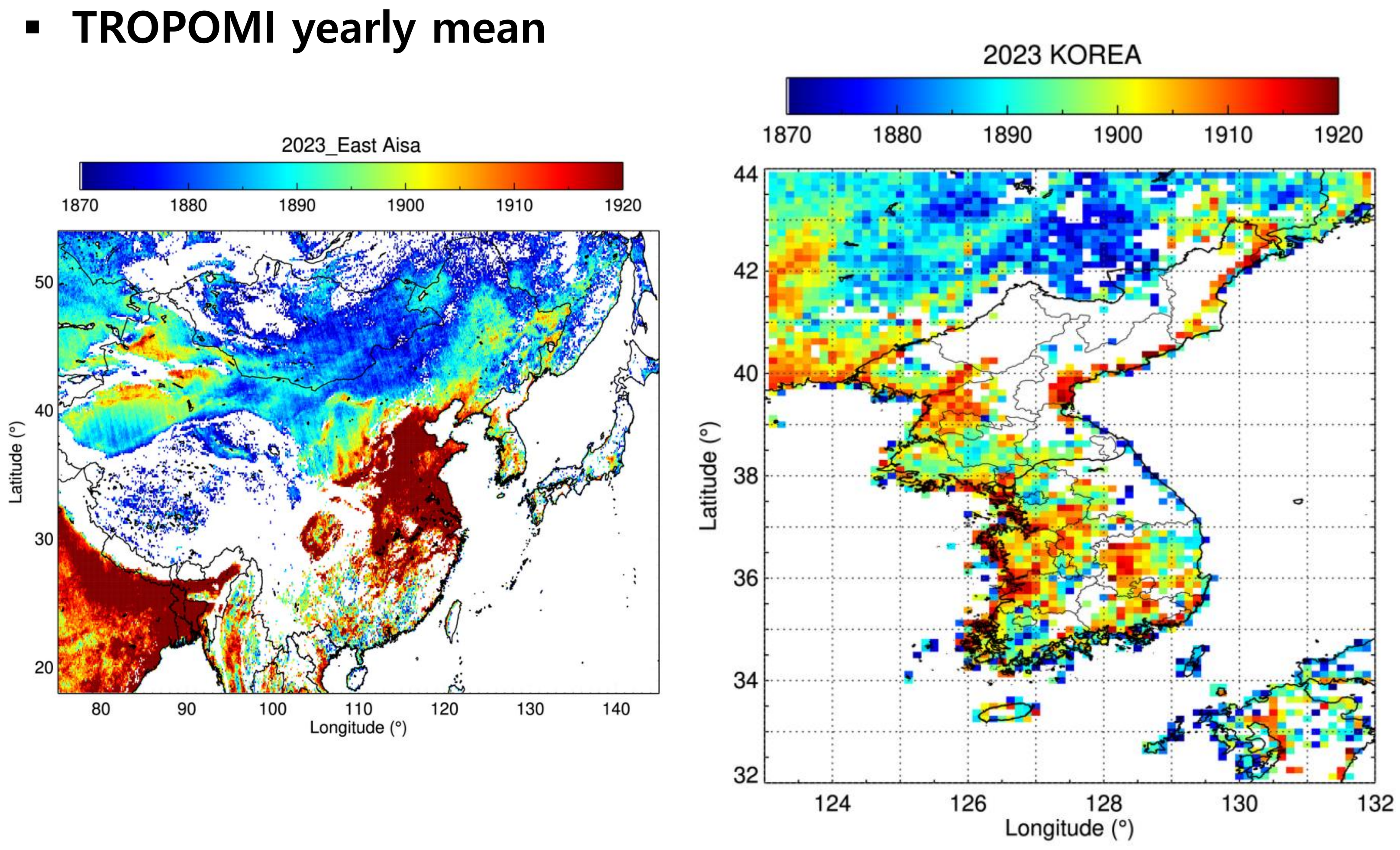
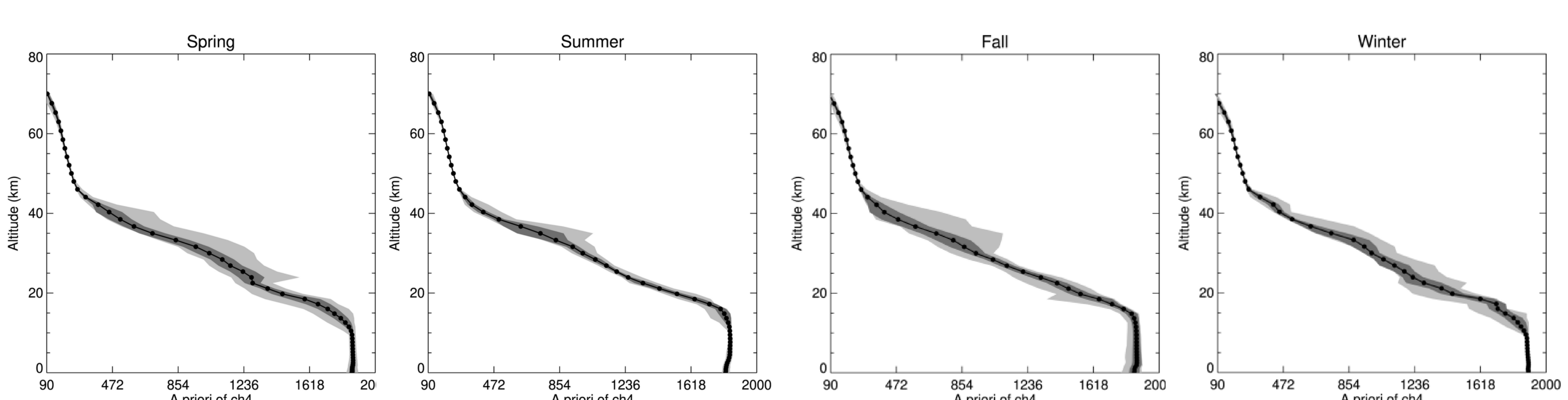


Figure 1. (Left panel) TROPOMI observations of the column-averaged dry methane mixing ratio (XCH_4) averaged in 2023 in Korea, (Middle panel) TROPOMI XCH_4 in 2023 in East Asia. (Right panel) TROPOMI XCH_4 from September to November in Korea.

- **TCCON profile**



User Requirement

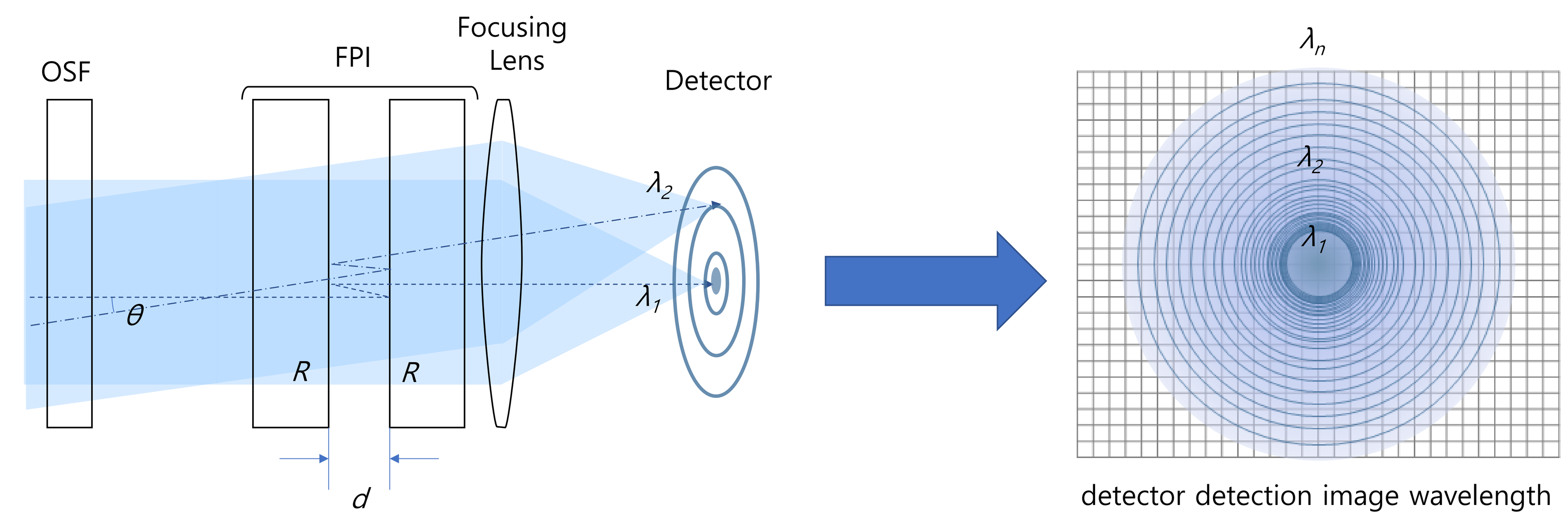
- **Cube-sat instrument**

Spectral range / Spectral resolution(FWHM)	1630 – 1680(SWIR) / 0.1nm (TBD)
Signal to noise ratio(SNR)	≥150
Swath	≥15km (TBD)
Spatial resolution	100 x 100m (TBD)
FWHM	0.1nm

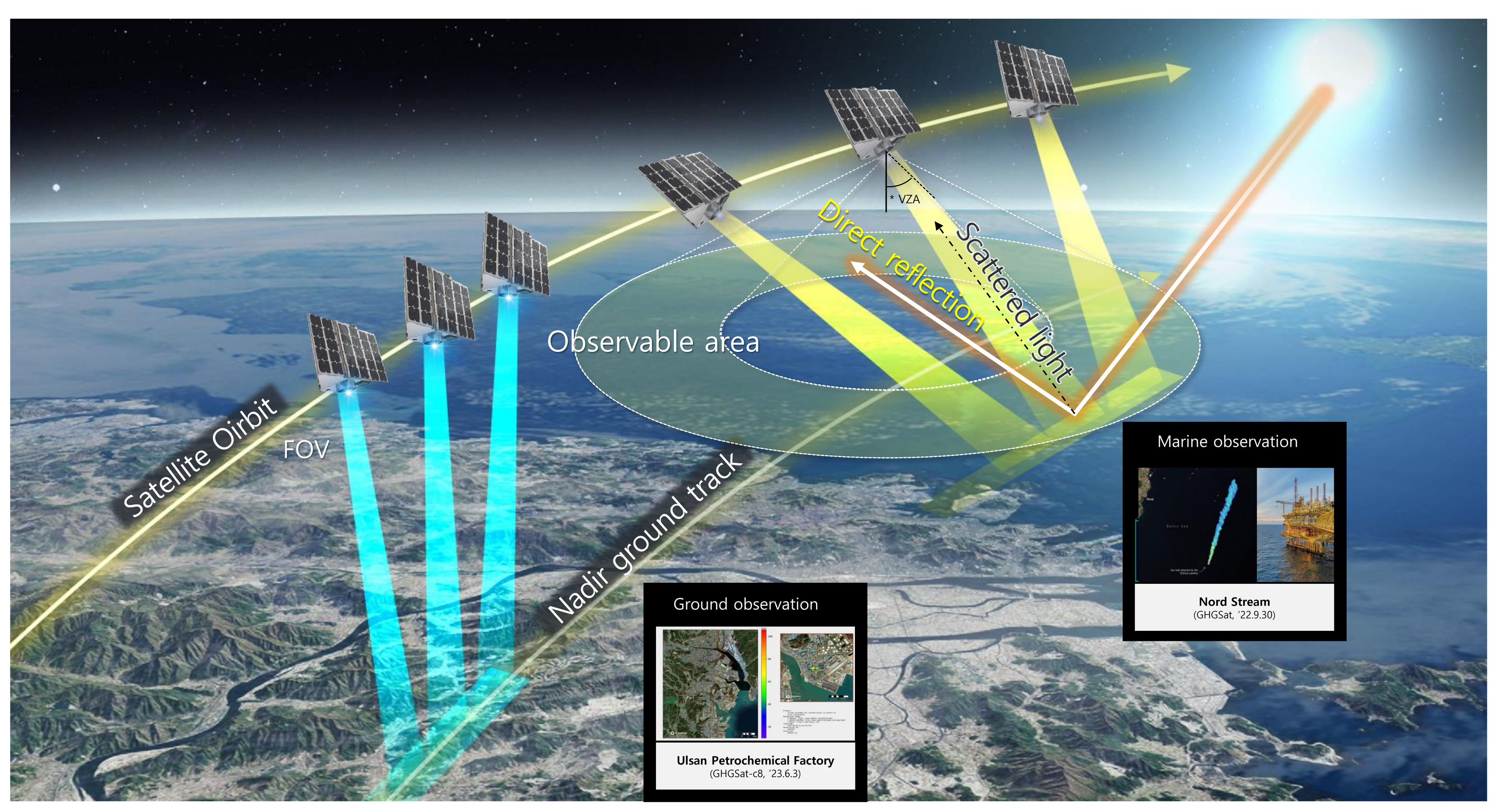
Measurement

- **Fabry-Perot Interferometer**

- Fabry-Perot Interferometer is an optical device used by GHGSAT to precisely measure the concentration of specific gases in the atmosphere. This instrument analyzes interference patterns of light to detect the spectrum of gases at various wavelengths



- **GHGSat Observation Principle**



Algorithm

Pre-Processing/Screening Data processing process	**The process of selecting observation data such as poor quality data, cloud pollution pixels, and large SZA.**
Retrieval Processing process	**Solar Model Instrument Model ↓ Radiance & Jacobian**
Quality evaluation	**The process of evaluating the final output based on a number of indicator such as DFS, Chi square, RMSE.**

The process of calculating radiance under satellite observation conditions and the Jacobian of each state vector using the preliminary data of state vectors, and calculating the concentration of greenhouse gases in the atmosphere through inverse analysis using the covariance matrix of state vector

State vector	Quantity	Meaning of State vector	A Priori
CO_2	20 levels	Volume Mixing Ratio on each level	CarbonTracker-Asia
H_2O	1	Multiplier to a priori profile	ECMWF
Temperature shift	1	Additive offset to a priori profile	ECMWF
Surface Pressure	1	Surface Pressure	ECMWF
Aerosols	19 layers (4 types)	AOD profiles on each level for user-defined types	AERONET DB
Surface Albedo	3 bands × 2 variables	Albedo at band centre and slope	Spectrum
Dispersion	3 bands × 2 variables	Spectral shift and squeeze	Spectrum
Total	54		

Reference and Acknowledgements

Dylan Jervis, Jason McKeever, Berke O. A. Durak, James J. Sloan, David Gains, Daniel J. Varon, Antoine Ramier, Mathias Strupler, and Ewan Tarrant : The GHGSat-D imaging spectrometer : https://doi.org/10.5194/amt-14-2127-2021

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