Commercial Satellite Data Acquisition Program

GHGSat Emission Quality Assessment Report

Goddard Space Flight Center
Greenbelt, MD

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Preface

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Abstract

The evaluation summarized in this report was conducted by subject matter experts (SMEs) funded by NASA's Commercial Satellite Data Acquisition (CSDA) Program. The SMEs evaluated the radiometric and geometric quality of GHGSat data for the NASA Earth science research and applications community. The results of the evaluation help to inform NASA program management on the quality of the data for NASA science.

Cover Art: Cover art is AI generated graphic using Microsoft Copilot Designer using term "commercial satellite constellation Earth observation across Atlantic AND Northern Hemisphere AND digital downlink"

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Change History Log

Revision	Effective Date	Description of Changes
1.0	03/22/2024	First Draft Completed

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Acronyms & Abbreviations

AOD	Aerosol Optical Depth
APA	Absolute Positional Accuracy
ARD	Analysis Ready Data
ATBD	Algorithm Theoretical Basis Document
BBR	Band-to-Band Registration
BRDF	Bi-directional Reflectance Distribution Factor
CE90	Circular Error at the 90th percentile
CF	Climate & Forecast (Metadata Convention)
CWV	Column Water Vapor
CEOS	Committee on Earth Observation Satellites
DEM	Digital Elevation Model
DESIS	DLR Earth Sensing Imaging Spectroradiometer
DN	Digital Number
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center)
DOI	Digital Object Identifier
EDAP	Earthnet Data Assessment Pilot
EO	Earth Observation
ESA	European Space Agency
ESF	Edge Spread Function
FAIR	Findable, Accessible, Interoperable and Reusable
FRM	Fiducial Reference Measurement
FWHM	Full-width Half-maximum
GRD	Ground Resolved Distance
GUM	Guide to the Expression of Uncertainty in Measurement
INSPIRE	Infrastructure for Spatial Information in Europe
ISS	International Space Station
L1	Level 1
L2	Level 2
LSF	Line Spread Function
MAIAC	Multi-Angle Implementation of Atmospheric Correction
MERRA	Modern Era Retrospective-analysis for Research and Applications
MODIS	MODerate-resolution Imaging Spectroradiometer
MSI	Multispectral Instrument (on Sentinel-2 platform)
MTF	Modulation Transfer Function
NAIP	National Agricultural Imagery Program
NASA	National Aeronautics and Space Agency
NOAA	National Oceanic and Atmospheric Administration
NPL	National Physical Laboratory, UK

OLI	Operational Land Imager (instrument on Landsat 8)
PCC	Pearson Cross Correlation
PSF	Point Spread Function
PUG	Product User Guide
PUM	Product User Manual
QA	Quality Assessment
QA4EO	Quality Assurance Framework for Earth Observation
QA4ECV	Quality Assurance Framework for Essential Climate Variables
RMSE	Root Mean Squared Error
RSR	Radiometric Spectral Response
S2	Sentinel-2
SBAF	Spectral Band Adjustment Factors
SI	Système International (International System of Units)
SNPP	Suomi-National Polar-orbiting Partnership
SSR	Sensor Spatial Response
SZA	Solar Zenith Angle
SR	Surface Reflectance
SRTM	Shuttle Radar Topography Mission
TOA	Top of Atmosphere
URL	Universal Resource Locator
VIIRS	Visible-Infrared Imaging Radiometer Suite
VZA	View Zenith Angle

Executive Summary

The CSDA Program was established to identify, evaluate, and acquire data from commercial sources that support NASA's Earth science research and application goals. NASA's Earth Science Division (ESD) recognizes the potential impact commercial satellite constellations may have in encouraging/enabling efficient approaches to advancing Earth System Science and applications development for societal benefit. Commercially acquired data may also provide a cost-effective means to augment and/or complement the suite of Earth observations acquired by NASA and other U.S. government agencies and those by international partners and agencies.

This quality of the GHGSat emission product was evaluated using input from the CSDA evaluation team, following a recently developed draft of the Joint NASA/ESA assessment guideline for greenhouse gas (GHG) emission data. The evaluation lead was enlisted to assess the fundamental quality of the GHGSat data using only results from the CSDA evaluation and documented descriptions of the GHGSat concentrations and emissions from GHGSat. Details about the utility of GHGSat data for NASA science is available in a separate CSDA Program Evaluation Report. This quality assessment reflects only the current understanding of the GHGSat constellation and reported measurements. Additional relevant input as well as changes to the technology could necessitate updates to this assessment.

At the time of the evaluation, GHGSat had a constellation of 10 satellites equipped with Fabrey-Perot hyperspectral imaging spectrometers, that have a field of view of 12 x 12 km, collecting 30 m resolution data with a nominal revisit period of approximately 14 days. GHGSat produces a Level-2 (L2) abundance dataset in GeoTIFF format, a Level-2 concentration map in PNG format, and a Level-4 (L4) emissions product as text (PDF, CSV). The abundance dataset includes per-pixel abundances of column average mixing ratio or column density, along with associated measurement errors. This document is an evaluation of the L4 methane emission estimation only. The assessment presented in this document is divided into two main parts: a documentation review and an assessment of the data. The documentation review in sections 2.1 through 2.3 includes the assessment of the information contained in the documents provided to the CSDA evaluation team by GHGSat. The grading of the information provided is given in the left portion of the Summary Product Evaluation Matrix shown in Figure 1. Sections 3 and 4 summarize the evaluation performed by the NASA teams using the data purchased through the CSDA program. This evaluation is summarized in the last column of Figure 1. Sections 3 and 4 provide more detailed explanations on the methods and the results of the assessment used to arrive at the validation summary column and are shown in the more detailed Validation Maturity Matrix (see Figure 2).
The GHGSat Level-2 concentration enhancement map identifies the target methane plume, which is highlighted from the background image using a pseudocolor mapping to depict concentration levels. Plumes of methane are then identified by first quantifying pixels with enhanced concentration values relative to background and then an algorithm is applied to determines if a coherent plume structure can be identified from these enhanced values.

The GHGSat L4 methane emissions estimate is provided in an excel spreadsheet and is typically accompanied by a Level-2 concentration map in PNG format and plume mask. The emissions are computed using the plume that is delineated in the Level-2 concentration map product.

Overall, the GHGSat emission product was rated as Good (possible scores are basic, good, excellent, and ideal). This grade was primarily dependent on the uncertainty characterization and validation approach. However, we note that the approach used for validation of this class of instruments is still nascent and the community is actively evaluating how to improve assessment of emission uncertainties and instrument sensitivity using fit-for-purpose validation experiments. Consequently, we should expect this grade to improve for GHGSat and other facility scale sensor platforms as the validation data sets and methodology matures.

1 Cal/Val Maturity Matrices

1.1 Summary Cal/Val Maturity Matrix

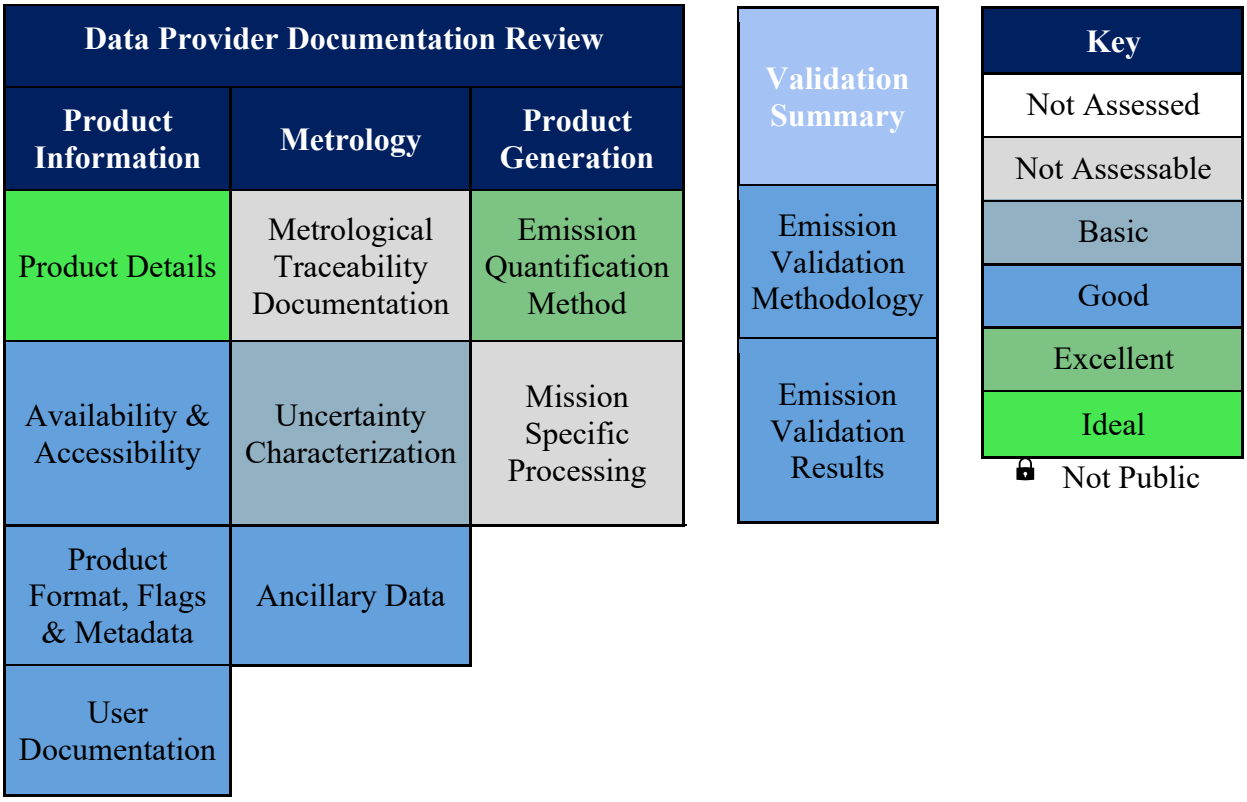

Figure 1. Summary Cal/Val Maturity Matrix.

1.2 Detailed Validation Maturity Matrix

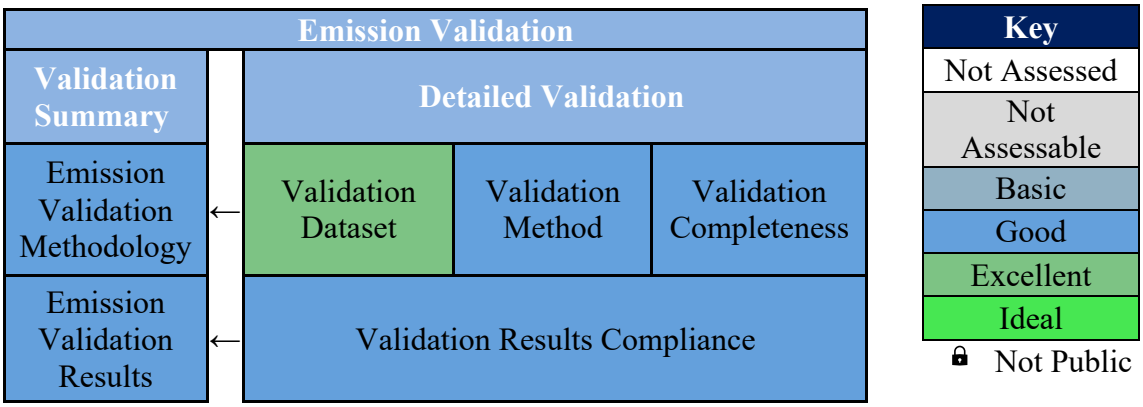

Figure 2. Detailed Validation Maturity Matrix, showing the Validation Summary column from the Summary Cal/Val Maturity Matrix.

1 Data Provider Documentation Review

2.1 Product Information

Product Details	
Grade: Ideal	
Justification	All required information was made available and was sufficient download and use the data.
Product Name	GHGSat emission rate
Sensor Name	GHGSat-C1, -C2, -C3, -C4, -C5, -C6, -C7, -C8, -C9, -C10
Sensor Type	Fabry-Perot Imaging Spectrometer
Mission Type	Hyperspectral SWIR Constellation
Mission Orbit	Sun Synchronous, low earth orbit, nearly global coverage (except 3.7deg cone at poles)
Product Version Number	Processing version 8.11.0
Product ID	CH4SM
Processing level of product	Level-4
Measurement Quantity Name	Emission rate
Measurement Quantity Units	Kg CH_4/hr
Measurement Quality	GHGSat claims a detection threshold of 100 kg (CH_4)/h at 3 m/s winds, with methane column density precision at 1% of background, and claims a non-specific sub-pixel (< 30 m) geolocation accuracy.
Spatial Coverage	~12 x 12 km
Point of Contact	Eric Choi (echoi@ghgsat.com)
Product locator (DOI/URL)	10.5194/amt-14-2127-2021; GHGSat document ID: GHG-1347-6001-c
Conditions for access and use	USG+ EULA, for research and scientific use only
Product Abstract	Emission rate from a targeted source estimated using abundance dataset(s) and applying dispersion modelling techniques.

Availability & Accessibility	
Grade: Good	
Justification	The data set meets some of the FAIR principles, they are easily findable, the metadata is well-organized, and defined, stored in JSON files. The data management plan is unknown at this time but the data package shows progress towards the FAIR principles. Metadata would not be described as rich.
Compliant with FAIR principles	No
Data Management Plan	Unknown
Availability Status	Data are available from GHGSat's Spectra interface after purchasing license for use.

Product Format, Flags and Metadata	
Grade: Excellent	
Justification	Emissions are a simple text CSV file (readable in Excel) with the appropriate error characteristics and metadata needed to identify likely source of emissions.
Product File Format	CSV
Metadata Conventions	Partial
Analysis Ready Data?	Yes

User Documentation		
Grade: Good		
Justification	GHGSat does not a have a document that is referred to as a user guide. Some product user guide type of information is available but is contained in multiple documents and within the literature. Documentation is up to date. An algorithm theoretical basis document (ATBD) is available but is proprietary.	
Document	***Reference***	***QA4ECV Compliant***
Product User Guide	"Data_File_Description", "Technical_Orientation", and "CSDA+Comprehensive+Data+Catalogue" were used. The latter also contained a peer-reviewed publication within.	No
ATBD	**GHGSat Document ID: GHG-1639-4001-a** A document that GHGSat considers to be proprietary.	No

2.2 Metrology

Metrological Traceability Documentation	
Grade: Not Assessable	
Justification	Not Assessable, no traceability chain documented
References	GHGSat ATBD (note this proprietary information)

Uncertainty Characterisation	
Grade: Basic+	
Justification	An uncertainty is provided but is related only to the wind measurements. Uncertainties from delineating the plume-mask are not included. The uncertainty of the wind fields are not included. Validation is by comparison to independent measurements (point release experiments), and these comparisons support the calculated uncertainties.
References	*N/A*

Ancillary Data	
Grade: Good+	
Justification	Wind fields are included with the product, but the wind field uncertainty is not.
References	GHGSat emissions product file

2.3 Product Generation

Emission Quantification Method	
Grade: Excellent	
Justification	Excellent: A standard approach is used for quantifying emissions as discussed in Varon et al. 2018 and in the ATBD. The grade cannot be ideal because the full uncertainty budget (winds + plume mask) are not included.
References	*Varon et al. 2018, and ATBD*

3 Detailed Validation – Emissions

As part of the NASA Commercial Satellite Data acquisition program, comparisons were made between GHGSat emission estimates with emission estimates from the NASA EMIT satellite as well as ground and aircraft-based estimates. In this next section we use these comparisons as the basis for grading the emissions validation.

3.1 Emission Validation Methodology

3.1.1 Validation Dataset

Excellent +: In this section, we grade the quality of the data set used by GHGSat for validating their emissions by comparing the results of their validation with the results of the CSDA funded analysis. The GHGSat team showed comparisons with single blind point-release experiments. As far as we can tell our results, using comparison to aircraft and ground-based emissions results, are consistent with theirs in that their calculated emissions are consistent with the validation data sets within uncertainties.

However, statistical comparisons between AVIRIS-NG data and GHGSat found that the stated performance for the probability of detection is likely too optimistic; this suggests that single-blind validation cannot adequately validate the GHGSat detectors.

3.1.2 Validation Method

Good: The single blind release experiments appear to be over a range of conditions; however, it was unclear if they were also temporally distributed to allow for how seasonal effects (e.g. through interference from water vapor and albedo on methane concentrations) affects the plume estimates.

3.1.3 Validation Completeness

Good: The single blind release experiments appear to be over a range of conditions; however, it was unclear if they were also temporally distributed to allow for seasonal effects (e.g. interference of water vapor and albedo on methane concentrations) affect the plume estimates.

3.2 Validation Results

3.2.1 Validation Results Compliance

Good +: The claimed mission performance for the Probability of Detection (POD) threshold is ~100 kg/hr. Using comparisons with aircraft-based plume data, one of the NASA of the evaluation teams showed that the actual POD threshold is likely between 250 to 350 kg/hr.

4 GHGSat Emission Product Overall Grade

Overall, the grade for the GHGSat emission product was rated as Good. While the product details and emission quantification method scored highly, the uncertainty characterization and validation generally received a good rating. We note however, that the approach used for validation of this class of instruments is still nascent and the community is actively evaluating how to improve assessment of emission uncertainties and instrument sensitivity using validation experiments. Consequently, we should expect this grade to improve for GHGSat and other facility scale instruments as the validation data set and methodology improves.

5 References

Alonso, K., Bachmann, M., Burch, K., Carmona, E., Cerra, D., de los Reyes, R., Dietrich, GHGSat Inc. (2022), "GHGSat Constellation Imagery and Data NASA CSDA Comprehensive Data Catalogue" Document No. GHG-1347-6001.

GHGSat Inc. (2023), "GHGSat Algorithm Theoretical Basis Document" Document No. GHG-01639-4001-a. May 2023.

Jervis, D. and McKeever, J. and Durak, B. O. A. and Sloan, J. J. and Gains, D. and Varon, D. J. and Ramier, A. and Strupler, M. and Tarrant, E. (2021). The GHGSat-D imaging spectrometer. Atmos Meas Tech **14**, 2127–2140.

McKeever and Jervis (2022), Validation and Metrics for Emissions Detection by Satellite [White paper].

Varon, D. J., McKeever, J., Jervis, D., Maasakkers, J. D., Pandey, S., Houweling, S., et al. (2019). Satellite discovery of anomalously large methane point sources from oil/gas production. Geophysical Research Letters, 46. https://doi.org/10.1029/ 2019GL083798