GHGSat Incorporated

DATA.SAT

PRODUCT SPECIFICATIONS

Document No. GHG-1500-6001

14 October 2021

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GHGSAT PRODUCT/DOCUMENT APPROVAL

Title: **GHGSat Incorporated**

DATA.SAT

Product Specifications

Document No.: **1500-6001**

Submission Date: **14 October 2021**

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CHANGE HISTORY

Version	Release Date	Notes
A	9 January 2015	Initial release
B	10 February 2016	General Updates
C	30 June 2016	Post-Launch Update
D	13 January 2017	General Updates
E	26 February 2018	Updated metadata table
F	27 March 2018	General Updates
G	20 August 2018	Updated for GHGSat-C1 and other general updates
H	19 February 2019	General Updates
I	26 April 2019	Updated due to changes in the Concentration Map format
J	3 February 2020	Update to remove CO2 product and add GHGSat-C2
K	08 May 2020	Updated Metadata and Delivery Format
L	14 October 2021	Adapted from GHG-1501-7003; general update

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1 SCOPE

GHGSat uses its own satellite and aircraft sensors to monitor greenhouse gas emissions from industrial facilities worldwide. GHGSat then uses proprietary analytics to combine measurements from its sensors with third-party data to provide actionable insights for customers.

GHGSat currently offers the following products and service for **methane**:

- DATA.SAT - high resolution satellite measurements (emissions rates greater than 100 kgCH4/hr)
- DATA.AIR - high resolution aircraft measurements (emissions rates greater than 10 kgCH4/hr)
- Global Survey Services – third-party satellite measurements (emissions rates greater than 3,000 kgCH4/hr),
- Emission Analytics – maps of concentrations, flares, hotspots, and emissions predictions

All of these products and services are delivered via SPECTRA, GHGSat's secure web portal.

GHGSat also offers a free service called PULSE, which is a global map of methane concentrations available at https:\\pulse.ghgsat.com

This document is the product specification for DATA.SAT.

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2 INTRODUCTION

DATA.SAT products include:

- Abundance datasets
- Concentration maps; and
- Emission rates

DATA.SAT products are generated using a hyperspectral imaging spectrometer operating in a narrow band of the short-wave infrared (SWIR) region of the electromagnetic spectrum. This sensor has both (i) very high spatial resolution (approx. 30 m), and (ii) very high spectral resolution, to enable high-precision measurement of vertical column densities of atmospheric gases of interest in each pixel within the instrument field of view.

An example of a DATA.SAT concentration map is shown in Figure 1.

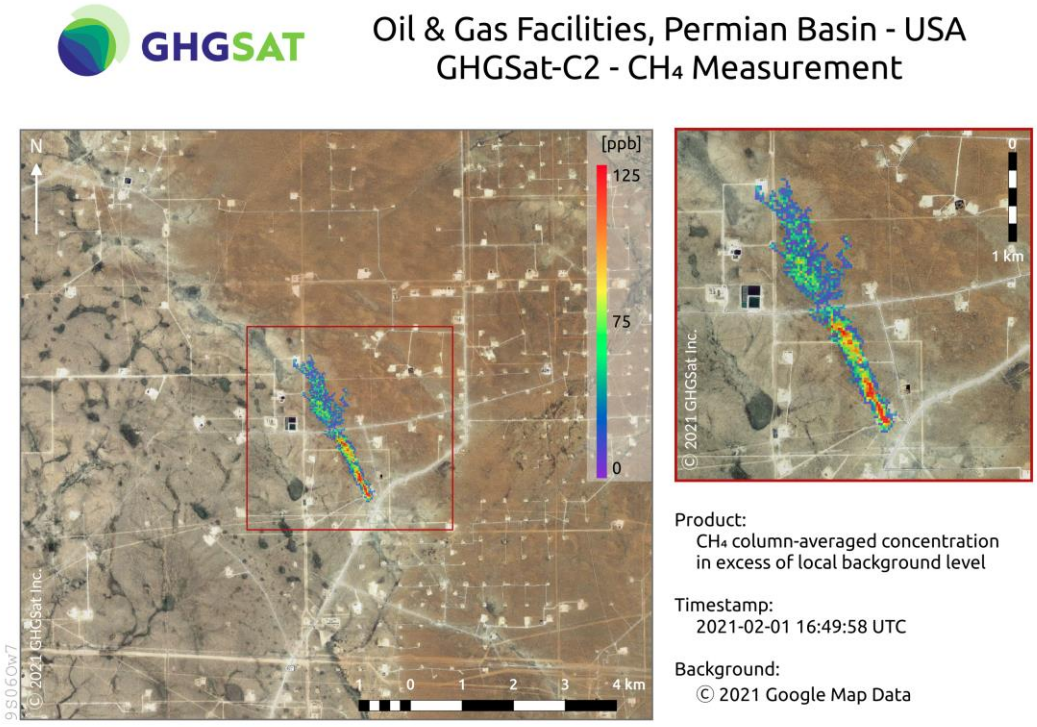

Figure 1: CH_4 Concentration Map

GHGSat launched its demonstration satellite (GHGSat-D, or "Claire") in June 2016. Follow-on satellites are built on lessons learned from GHGSat-D to (i) measure greenhouse gases emissions from industrial facilities, (ii) provide daily revisits, and (iii) provide operational redundancy. GHGSat's first commercial satellites, GHGSat-C1 ("Iris") and GHGSat-C2 ("Hugo") were launched in September 2020 and January 2021, respectively. Several more satellites are now on order, with a total of 10 commercial satellites expected to be in orbit by 2023.

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2.1 Contents

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2.2 Acronyms

EOSDIS	NASA Earth Observing System Data and Information System
EULA	End-User License Agreement
FOV	Field of View
GHG	Greenhouse Gas
GPS	Global Positioning System
LTDN	Local time of the descending node
SSO	sun-synchronous low Earth orbit
SWIR	Short-wave infrared
WAF-P	Wide-Angle Fabry-Pérot

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3 GHGSAT SATELLITES

3.1 GHGSat Constellation

GHGSat satellites are designed to measure greenhouse gas emissions from target sites. Each satellite has sufficient capacity to measure thousands of sites per year, with an average revisit period of two weeks.

Satellite Property	GHGSat-D Information	GHGSat-C1 Information	GHGSat-C2 Information
Ownership	GHGSat Inc.	GHGSat Inc.	GHGSat Inc.
Nickname	"Claire"	"Iris"	"Hugo"
Date of launch (YYYY-MM-DD)	21 June 2016	02 September 2020	24 January 2021
Launcher	PSLV-C34	Arianespace Vega	SpaceX Falcon 9
Expected lifetime	4 years	4 years	4 years
Orbital altitude above Earth surface	Approx. 500 km in sun-synchronous orbit	Approx. 500 km in sun-synchronous orbit	Approx. 500 km in sun-synchronous orbit
Revisit period	< 14 days (typical)	< 14 days (typical)	< 14 days (typical)
Primary Sensor			
Name	SWIR-1: WAF-P Imaging Spectrometer	SWIR-2: WAF-P Imaging Spectrometer	SWIR-3: WAF-P Imaging Spectrometer
Sensor Type	Optical	Optical	Optical
Bands and spectral ranges	SWIR 1600-1700 nm, multiple bands in a proprietary configuration, unpolarized	SWIR 1600-1700 nm, multiple bands in a proprietary configuration, unpolarized	SWIR 1600-1700 nm, multiple bands in a proprietary configuration, unpolarized
Spatial Resolution	< 50 m	Approx. 30m	Approx. 30m
Swath width	< 15 km	< 15 km	< 15 km
Depth of imaging	12 bit	12 bit	12 bit
Geometric accuracies	Features can be georeferenced to an accuracy of approx. 30 m or less	Features can be georeferenced to an accuracy of approx. 30 m or less	Features can be georeferenced to an accuracy of approx. 30 m or less
Species Measured	CH4	CH4	CH4

Table 1: GHGSat Satellite Sensors

3.2 Image Processing Overview

The primary sensor on all GHGSat satellites is a Wide-Angle Fabry-Perot ("WAF-P") Imaging Spectrometer. This primary sensor produces a stack of overlapping images analogous to a hypercube acquired within <30 seconds. This image sequence contains spatially resolved spectral information from hundreds of wavelengths within our passband. Once downloaded, the images are corrected for sensor response and other instrument-level effects. The gas column densities and surface reflectance

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information are then retrieved for each ground pixel using a measurement model which includes surface, instrument and atmospheric contributions to the spectral radiance. Finally, the resulting arrays are georeferenced, giving the "Abundance Dataset" for CH_4.

The Level 2 products cover a programmable domain size, which is nominally approximately 12 km x 12 km. Combined with GHGSat's spatial resolution of approx. 30m, this allows customers to easily identify gas plumes emitted from specific industrial facilities within the domain, as the high-resolution plume image stands out from the surrounding background.

The reflectance and abundance products can be combined into a high readability "Concentration Map" for human interpretation.

The abundance datasets from multiple observations of a given site can be combined to form a monitoring product for semi-automatic detection of emitter activity or large changes in emission rates using pre-determined thresholds.

Abundance datasets also allow emission rates to be estimated for individual sources. Source rate retrievals are done using site information and weather data from global meteorological models or local weather stations.

GHGSat's imagery and data products are summarized in Table 2 below, using definitions consistent with the NASA Earth Observing System Data and Information System (EOSDIS).

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Level	EOSDIS Definition	GHGSat Products	Product Description
Level 2	Derived geophysical variables at the same resolution and location as the source data.	Abundance Dataset	Set of (a) per-pixel abundances [column average mixing ratio in ppb (parts per billion) or column density in mol/m^2] for CH_4, and (b) per-pixel measurement error expressed as a standard deviation, for a single site, on a single satellite pass and (c) quality flag layer
Level 2	Derived geophysical variables at the same resolution and location as the source data.	Concentration Maps	High readability pseudocolor map in PNG format. Background image: surface reflectance Foreground: CH_4 abundance (ppb or mol/m^2) The concentration map file is included when an emission is positively identified.
Level 4	Model output or results from analyses of lower level data (ie. variables derived from multiple measurements)	Emission Rates	Emission rate from targeted source estimated using abundance dataset(s) and applying dispersion modelling techniques

Table 2: DATA.SAT Products

3.3 Conversion of pixel indices to geo-locations

Georeferencing assigns real-world coordinates to each pixel of a raster. Image location is determined through the satellite's GPS output, time of acquisitions, and the number of frames taken.

GHGSat uses a georeferencing module to reference the scene image against a base image such as Landsat.

Further supporting details, including software tools and algorithms applied (where available to GHGSat) can be provided upon request.

Metadata delivered with product imagery contains a transformation matrix that provides details about the conversion performed to assign pixel indices to geo-locations.

3.4 Orbit Considerations

GHGSat satellites are typically in a sun-synchronous low Earth orbit (SSO) with a period of <100 minutes, an altitude between 500 km and 700 km and a local time of the descending node (LTDN) between 9:30 and 14:00.

SSO's are designed to ensure that observations are always made at the same local time of day at any site on the surface of the Earth. This time is roughly defined by the LTDN of the orbit.

While the orbit ensures a consistent time of day for all observations, GHGSat-D, GHGSat-C1 and GHGSat-C2 operations remain subject to seasonal variations in solar elevation angle at any given site. For example, the sun will be below the horizon for a 09:30 pass above any site with latitude above 60 deg N

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in December. Since performance of GHGSat's primary sensor depend on solar elevation angle, observations at higher-latitude targets do not produce satisfactory results during the full year.

GHGSat staff reviews orbit considerations for specific sites on a case-by-case basis.

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4 PRODUCT SPECIFICATIONS

4.1 Level 2 Products

GHGSat offers the Level 2 products for a single observation or a full year as described in Table 3 :

Commercial Satellite Imagery – Products	Single Observation	Full-Year
Abundance Dataset	Set of (a) CH_4 per-pixel abundance (ppb or mol/m^2), (b) per-pixel measurement error expressed as a standard deviation, for a single site, on a single satellite pass and (c) quality flag layer.	Collection of as many scene datasets as cloud cover will allow, for a single site over a full year, up to a maximum of 10 collections per year.
Concentration Map	A high readability pseudocolor map combining (a) surface reflectance and (b) excess CH_4 abundance in parts per billion (ppb) or in mol/m^2.	Generation of as many concentration maps as cloud cover will allow, for a single site over a full year, up to a maximum of 10 concentration maps per year.

Table 3: Summary of Level 2 Products

Notes:

(i) Products are provided on a pre-defined area (scene) basis only, for the full sensor field of view
(ii) "Site" refers to a known geographic location targeted by GHGSat; the site will be within the scene, and GHGSat will make its best effort to position the site within the scene to best measure any emission plume.
(iii) The products offered are for the GHGSat Constellation
(iv) GHGSat will not set predetermined cloud cover limits; in general, GHGSat's high spatial resolution can enable measurement of site emissions even if a significant proportion of the scene is cloud-covered; GHGSat will provide calculated measurement precisions based on a range of retrieval parameters, including cloud cover.

Additional technical parameters for Level 2 products are provided in Table 4 below.

Property	Product A.2.0_CH4	Product A.3.0_CH4
Product Name	***Abundance Dataset – CH4***	***Concentration Map – CH4***
Constellation	GHGSat	GHGSat
Sensor name	SWIR	SWIR
Band(s) / Beam mode(s) and polarization	SWIR 1600-1700 nm, multiple bands in a proprietary configuration, unpolarised	SWIR 1600-1700 nm, multiple bands in a proprietary configuration, unpolarised

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Property	Product A.2.0_CH4	Product A.3.0_CH4
Spatial resolution(s)	< 50 m	< 50 m
List of geometric corrections performed	Radial distortion, perspective projection	Radial distortion, perspective projection
List of radiometric corrections performed	Detector pixel response, ghosting, spectral response, atmospheric correction including trace gas modeling and surface reflectance	Detector pixel response, ghosting, spectral response, atmospheric correction including trace gas modeling and surface reflectance
Data format(s): Default and/or Options	GeoTIFF (32-bit floating-point); optional GeoTIFF (16-bit)	PNG plus A.2.0 products (GeoTIFF by default)
Time period covered by the catalogue data	July 2016-Present	July 2016-Present
Species Measured	CH_4	CH_4
Measurement Period	Single Scene	Single Scene

Table 4: GHGSat Level-2 Products

Note: For products A.2 and A.3, GHGSat differentiates between "complex source" and "point source", defined as follows:

- A "point source" is typically a single physical feature (e.g. an industrial chimney/stack, or group of stacks within a few hundred meters of each other) emitting greenhouse gases at an industrial facility.
- In general, a "complex source" can be an area source (e.g. tailings ponds, mine faces, hydroelectric reservoirs), line source (e.g. pipelines), or other unique source (e.g. airport departure and approach corridors, shipping lanes, etc.).

The distinction between a point source and a complex source is made at GHGSat's sole discretion. Product numbers for complex sources begin with A.2.1 or A.3.1, and for point sources begin with A.2.2 or A.3.2. The GHGSat constellation includes GHGSat-D, GHGSat-C1 and GHGSat-C2 with their respective SWIR sensor.

4.2 Level 4 Products

GHGSat estimates of instantaneous emission rates (also referred to as "source rates" for plumes detected from targeted sites.

Emission rates are delivered as a PDF and a CSV file giving the emission rate estimates, their uncertainties and key dispersion parameters for each observation. Emission rates are delivered as a bundle with Level 2 products.

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Property	**Product D.1.0_CH4**
Product Name	***Emission Rate – CH4***
Constellation name	GHGSat
Sensor name(s)	SWIR
Spatial resolution	See A.2.0
Product Description	Emission rates estimated using the abundance dataset from each scene and applying source rate retrieval techniques
Projection information if applicable	See A.2.0
Data format(s): Default and Options	PDF + CSV + A.2.0 formats
Species Measured	CH_4
Measurement Period	Instantaneous (Single Scene) or full year

Table 5: Level 4 Products – Emissions Rates

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4.3 Quality Attributes

4.3.1 Accuracy & Precision

Each Abundance Dataset includes a set of (a) per-pixel column density arrays (mol/m^2) for a single species, (b) corresponding per-pixel measurement error estimate expressed as a standard deviation (mol/m^2), for a single site, on a single satellite pass and (c) quality flags layer indicating pixels quality.

Error analysis shows that for GHGSat-D most of the uncertainties are due to instrument errors, shot noise accounting for a smaller fraction of the total error. As such, the error values are highly scene dependent. Follow-up missions such as GHGSat-C1 will have lower instrument errors and operate closer to the shot noise limit.

Note that GHGSat-D's SWIR-1 sensor is designed to provide a measurement of the excess CH_4 in due to local sources with respect to the surrounding background within a given scene, so that the background levels should not be relied on for absolute accuracy.

For further clarity, GHGSat primary sensors are not designed to perform absolute measurements of vertical column densities.

GHGSat-D's C&A-1 sensor is operational but not part of the retrieval process. GHGSat-C1 and GHGSat-C2 each have a visible sensor on board.

4.3.2 Clouds & Aerosols

GHGSat's emissions retrieval algorithms are applicable to scenes partially obstructed by cloud cover, although the extent to which the presence of visible clouds impacts the error levels in the unobstructed pixels is difficult to quantify.

Spectral adjustment models in GHGSat's abundance dataset retrieval algorithm provide some degree of immunity against the effects of thin clouds and aerosols. While atmospheric aerosol loading and thin clouds have little effect on the visibility of plumes with respect to the surrounding background, they do have the potential to affect the retrieved differential column quantities and therefore the inferred emission rates. For this reason, GHGSat determines acceptable cloud and aerosol environments on a case-by-case basis for emission retrievals.

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5 PRODUCT LICENSING

GHGSat licenses DATA.SAT products in accordance with a standard End-User License Agreement ("EULA") for commercial satellite imagery or data. GHGSat will license DATA.SAT products subject to applicable license classes.

5.1 License Classes

5.1.1 Commercial Licenses

A single license class is currently available to commercial customers, which provides a limited license to the customer legal entity and its legal affiliates.

5.1.2 Government Licences

GHGSat will comply with Government procurement guidelines, on a case-by-case basis. In Canada, GHGSat offers a range of license classes based on its national master standing order (Ref. E60SQ-120001).

5.1.3 Public Licenses

GHGSat does not offer DATA.SAT products available under a Public Good License. GHGSat nevertheless reserves the right, at its sole discretion and at any time, to release selected products under a Public Good License.

5.2 Holdback

5.2.1 Commercial Customers

For commercial customers, GHGSat reserves the right, at its sole discretion and at any time, to provide a temporary (i.e. not perpetual) exclusive license to any customer for selected products measured by GHGSat or derived from such measurements for selected target sites (the "Exclusive Products"), for an additional fee (the whole being the "Temporary Exclusive License"). A Temporary Exclusive License will provide highest tasking and delivery priority to the licensee for the Exclusive Products, reserve the Exclusive Products for the sole use of that licensee, and withhold information about the Exclusive Products from GHGSat's public catalogue.

5.2.2 Government Customers

Government procurement rules preclude GHGSat from offering exclusivity options to Government customers. GHGSat instead offers a catalogue holdback option for each order, which withholds information about that order from GHGSat's public catalogue. Government customers can then also select the highest tasking and delivery priority for that site to ensure that they always get measurements of the site before any other customer.

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6 PRODUCT DELIVERABLES AND NAMING

6.1 Deliverables

Level 2 and Level 4 products are delivered as a bundle for each satellite measurement. The bundle includes the abundance dataset for the measurement, as well as concentration maps and emission rate estimates for each plume detected.

In addition to this bundle, GHGSat delivers a plume raster for each emission detected.

Finally, GHGSat provides a monthly report of all measurements performed of customer sites.

6.2 Naming

The file naming convention for the product deliverables consists of five subfields separated by underscores and keys as follows:

Sensor_Aquisitiondate_Processingdate_OBSID_SUFFIX

Where:

Sensor is the abbreviation identifier for the satellite sensor

D: GHGSat-D or 'Claire'

C1: GHGSat-C1 or 'Iris'

C2: GHGSat-C2 or 'Hugo'

Aquisitiondate is the acquisition date in YYYYMMDD format

Processingdate is the data processing date in YYYYMMDD format

OBSID is the observation identification composed of 7 alphanumeric characters

SUFFIX is the type of deliverable as follow:

META: The Meta file in Text format

BRW: The Albedo image in PNG and WLD format

ALB: Surface Reflectance in U16 format

CH4: Methane Measurement in TIFF/F32 or U16

CH4CM: Concentration Map in PNG format

CH4SR: Source Rate in Excel/CSV format

CH4ER: Error CH4 Measurement in TIFF/F32 or U16 format

FLG: Quality Flags in TIFF/U8 format

For the plume raster deliverable has, the naming definition is extended with two additional fields to consider the site and the plume identification as follow:

Sensor_Aquisitiondate_Processingdate_OBSID_SITEID_PLUMEID_SUFFIX

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Where:

SITEID is the Site identification number

PLUMEID is the Identifier for the Emission (Plume)

SUFFIX is the type of deliverable as follow

PLM: Plume Raster

The DATA.SAT file naming convention for the report deliverables consists of three subfields separated by underscores and keys as follows:

Product Order_Report Date_SUFFIX

Where:

Product Order is the Customer Product Order number

Report_date is the Report Date in YYYYMMDD format

SUFFIX is the type of Report as follow:

MONR: Monthly Report in PDF format

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7 PRODUCT DELIVERY

7.1 Product Delivery Package

The file delivery package shall include the items in Table 6.

Item	Contents
Imagery / Data	The image or data product, ordered as per Call-up, with unique ID for each image / data product
Metadata	Metadata describing the imagery / data
	Browse Image (for imagery)
	End User License Agreement (text)
	License Class as per Call-up
	Ordering information
	Meta data for additional description of the imagery / data
Additional Information	Any associated processing files and documentations to help the user to understand the Product quality and facilitate data use.

Table 6: GHGSat Product Delivery Package

7.2 Delivery methods and file format

7.2.1 Commercial Customers

GHGSat will deliver products via its online Delivery system. Delivery provides:

- Visibility to GHGSat's public catalogue
- Access to customer-specific observation products and data

Each customer will be provided a unique, password-protected access to Delivery.

GHGSat will provide email notification of product and data delivery in Delivery to designated customer points of contact.

Note that customers may request alternative delivery methods on a case-by-case basis, including FTP/SFTP.

7.2.2 Government Customers

GHGSat will comply with Government procurement guidelines, on a case-by-case basis. In Canada, GHGSat will deliver product packages in accordance with its National Master Standing Order (Ref. E60SQ-120001).

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8 METADATA

This Metadata uses json file format.
The Metadata version 2.0 is described in the table below:

Properties	Required(R) or Desirable(D)	Metadata Format	Typical Data
Metadata Version	R	**metadata_version**	2.0
Sensing Platform -Satellite or Constallation and Sensor name and wavelength	R	**plateform_type** **name** **wavelength_min** **wavelength_max**	satellite GHGSat-C1 1600 1700
Product Order Ordering and contact information, including: • Supplier order number • Client order number • Product id • Technical Authority email • Technical Authority Website URL • Phone number of the Technical Authority	D	**order_supplier** **order_client** **order_product** **tech_auth_email** **tech_auth_url** **tech_auth_phone**	5Py05JW201029 2938888404 001 operations@ghgsat.com https://www.ghgsat.com +1 438-500-6700
License • License Class • File Source • Source Website URL • License file name • License Language (en-english) • License file size • License Version • SHA-256 license key	D	**class** **originator** **originator_url** **filename** **language** **size_bytes** **version** **sha256 (license key)**	Commercial GHGSat https://www.ghgsat.com license.txt en 8214 20181017 12bd3001ce384dde3936e7a12c62815b126624b6fe1997d4e6b1fe0db41085cf
Observation • Acquisition Time (UTC) (Start/Stop) Geometry: Sensor viewing / incidence angle • Sun Zenith • Sun Azimuth • Line of Sight Zenith • Line of Sight Azimuth • Satellite Height (m)		**start_time_unix** **stop_time_unix** **start_time_iso8601** **stop_time_iso8601** **sun_zenith_deg** **sun_azimuth_deg**	1600759366.0 1600759386.0 2020-09-22T07:22:46+00:00 2020-09-22T07:23:06+00:00 40.304 159.243

For more information contact the author directly: operations@ghgsat.com

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Properties	Required(R) or Desirable(D)	Metadata Format	Typical Data
		los_zenith_deg	18.139
		los_azimuth_deg	285.753
		satellite_height_meters	548113.47
Conversion Factors Unit conversions • Mol/m2 to ppb • ppb to Mol/m2		**ch4_molm2_to_ppb**	2794.839
		ch4_ppb_to_molm2	0.0003578
Processing Groups Processing information, including: List of processing levels, processor name and version		**levels**	L0
		processor	GHGSat-Toolchain
		processor_version	8.11.0
Layers •Spatial resolution / Pixel spacing •Projection Information •Image Corner Coordinates		**filename**	C1_20201014_20201016_hJr59R6_ALB.tif
		auxiliary_filenames	
		name	Surface Reflectance
		gas	
		file_format	GeoTIFF
		rows	550
		columns	692
		size_kbytes	334454567
		unit	Ppb
		datatype	F32
		processing_level	L2B
		gsd_x_meters	35.08627432077034
		gsd_y_meters	35.08627432077034
		transformation	
		abcd	35.0862,0.0,0.0,245378.7086
		efgh	0.0,-35.0862,0.0,4278564.6581
		ijkl	0.0,0.0,0.0,0.0
		mnop	0.0,0.0,0.0,0.0
		crs	
		epsg	32640

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Properties	Required(R) or Desirable(D)	Metadata Format	Typical Data
		wkt	
		bounding_box	
		lat_min	38.451991464205975
		lat_max	38.61907929499025
		lon_min	54.075421413929625
		lon_max	54.36036859019196
		min	0.1233
		max	0.8934
		mean	0.4568
		mean_background	
Files		**Filename**	C1_20201014_20201016_hJr59R6_BRW.png
		auxiliary_filenames	C1_20201014_20201016_hJr59R6_BRW.wld
		name	Browse image
		file_format	PNG with ESRI World File
		size_kbytes	65465488
		processing_level	L2B

Table 7: GHGSat Metadata Format

The metadata details above should be sufficient to allow a professional programmer to read the volume and transform its contents into a sensible image. Further details can be provided on a case-by-case basis.

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