GHGSat Inc.

GHGSAT-C1/C2 SATELLITE IMAGERY AND DATA
ESA THIRD PARTY MISSIONS PRODUCT SPECIFICATION

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17 February 2021

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GHGSAT PRODUCT / DOCUMENT APPROVAL

Title: **GHGSat Inc.**

GHGSat-C1/C2 Satellite Imagery and Data

ESA Third Party Missions Product Specification

Document No.: **1301-6001**

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CHANGE HISTORY

Version	Release Date	Notes
A	14 January 2020	Initial release
B	1 February 2021	Update to customize for GHGSat-C1 data for ESA TPM
C	17 February 2021	Clarification to include GHGSat-C2 data products (identical to C1)

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1 INTRODUCTION

GHGSat Inc., the only company with its own satellites for measuring greenhouse gas emissions from targeted industrial facilities anywhere in the world, is pleased to provide high-resolution data from the GHGSat-C1 "Iris" and GHGSat-C2 "Hugo" satellites for assessment by the European Space Agency (ESA) under its Third Party Missions (TPM) programme.

GHGSat-C1 and GHGSat-C2 collect data using a hyperspectral imaging spectrometer operating in a narrow band of the short-wave infrared (SWIR) region of the electromagnetic spectrum. This primary sensor has both (i) very high spatial resolution and (ii) very high spectral resolution to enable high-precision measurement of vertical column densities of atmospheric gases of interest in several hundred thousand pixels within the instrument field-of-view (approximately 12 km × 12 km).

An example of a resulting end product from GHGSat-C1 with commercial satellite imagery in the background is shown in Figure 1.

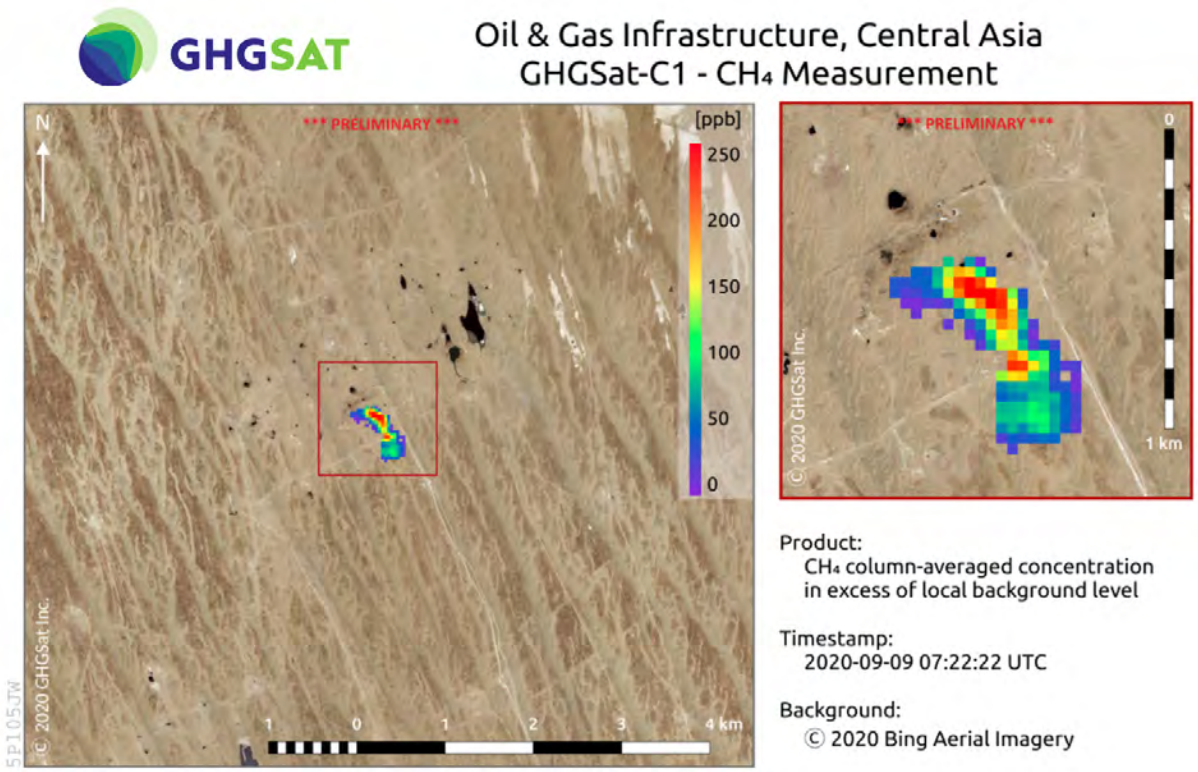

Figure 1: CH_4 Concentration Map – Central Asia

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1.1 Contents

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1.2 Acronyms

AQG	air quality gas
ESRI	Environmental Systems Research Institute
EOSDIS	Earth Observing System Data and Information System (NASA)
EULA	end-user license agreement
FOV	field-of-view
GHG	greenhouse gas
GPS	Global Positioning System
SSO	Sun-synchronous orbit
SWIR	shortwave infrared
WAF-P	Wide-Angle Fabry-Pérot

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2 SATELLITE AND INSTRUMENT SPECIFICATIONS

The specifications of the GHGSat-C1 and GHGSat-C2 satellites and instruments are summarized in Table 1 below.

Property	GHGSat-C1 Information	GHGSat-C2 Information
Ownership	GHGSat Inc.	
Launch Date	2 September 2020	24 January 2021
Design Lifetime	4 years (minimum)	
Nominal Altitude	523 km	530 km
Revisit Period	<14 days (typical)	
Primary Sensor		
Name	SWIR-2: WAF-P Imaging Spectrometer	
Sensor Type	Optical	
Bands and Spectral Ranges	SWIR 1635-1675 nm, multiple bands in a proprietary configuration, unpolarized	SWIR 1660-1675 nm, multiple bands in a proprietary configuration, unpolarized
Spatial Resolution	<30 m (orbit dependent)	
Field-of-View	12 km × 12 km	
Swath Width	<20 km	
Geometric Accuracy	<5 m	
Column Density Precision	1% of background (goal for methane)	
Detection Threshold	100 kg/hour in 3 m/s wind (for methane)	
Sampling Depth	12 bit	
On-Board Calibration Source	Yes	
Along-Track Imaging Capacity	Yes	
Sensor Pointing (spacecraft slew)	±15° off nadir, along and cross-track	
Previous Flight Heritage	GHGSat-D	GHGSat-C1
Secondary Sensor		
Name	VIS-1: Visible	
Sensor Type	Optical	
Bands and Spectral Ranges	Visible	
Spatial Resolution	<20 m	
Swath width	<35 km	
Sampling Depth	12 bit	

Table 1: GHGSat-C1 and GHGSat-C2 Satellite and Instrument Specifications

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3 IMAGE PROCESSING

3.1 Overview

The primary sensor aboard GHGSat-C1 and GHGSat-C2 is a Wide-Angle Fabry-Pérot (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 the passband. Once downloaded, the images are corrected for sensor response and other instrument-level effects. The gas column densities and surface reflectance information is then retrieved for each ground pixel using a measurement model that includes surface, instrument, and atmospheric contributions to the spectral radiance. Finally, the resulting arrays are georeferenced to give the surface reflectance image and the abundance dataset for the greenhouse gas of interest (typically CH_4 for GHGSat-C1 and GHGSat-C2).

The Level 2 products cover a field-of-view of approximately 12 km × 12 km. Combined with unprecedented spatial resolution of <30 m, this allows investigators to easily identify gas plumes emitted from specific industrial facilities within the field-of-view, 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-C1 and GHGSat-C2 imagery and data products are summarized in Table 2 below, using definitions consistent with the NASA Earth Observing System Data and Information System (EOSDIS).

Level	EOSDIS Definition	GHGSat-C1/C2 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 (ppb or mol/m^2) for a single species, and (b) per-pixel measurement error expressed as a standard deviation.
Level 2	Derived geophysical variables at the same resolution and location as the source data.	Concentration Maps	High readability pseudocolour map combining (a) surface reflectance, and (b) column density expressed in ppb or mol/m^2 for a single species.
Level 4	Model output or results from analyses of lower level data (i.e. variables derived from multiple measurements).	Emission Rates	Emission rate from targeted source estimated using abundance dataset(s) and applying dispersion modelling techniques.

Table 2: GHGSat-C1 and GHGSat-C2 Imagery and Data Products

3.2 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. Metadata delivered with product imagery contains a transformation matrix that provides details about the conversion performed to assign pixel indices to geo-locations. Further supporting details, including software tools and algorithms applied (where available to GHGSat) can be provided upon request.

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4 SATELLITE IMAGERY AND DATA PRODUCT SPECIFICATIONS

4.1 Overview

GHGSat offers abundance, concentration, and emission datasets as described below in Table 3:

GHGSat-C1/C2 Products	Description of Observation
Abundance Dataset	Set of (a) per-pixel column density (ppb or mol/m^2) for a single species, and (b) per-pixel measurement error expressed as a standard deviation for a single site on a single satellite pass
Concentration Map	High readability pseudocolour map combining (a) surface reflectance, and (b) excess column-averaged concentration expressed in ppb or mol/m^2 for a single species.
Emission Rates	Instantaneous emission rate from targeted source estimated using abundance data from a single satellite pass and applying dispersion modelling techniques. The delivered product includes the emission rate estimate with uncertainty and key dispersion parameters as well as the abundance dataset used for the emission estimate.

Table 3: Summary of GHGSat-C1 and GHGSat-C2 Satellite Imagery 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) 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.

4.2 Abundance and Concentration Products (Level 2)

Properties of the GHGSat-C1/C2 abundance and concentration products are summarized in Table 4.

Property	Product A.2.0_CH4	Product A.3.0_CH4
Product Name	***Abundance Dataset – CH4***	***Concentration Map – CH4***
Satellite	GHGSat-C1/C2	GHGSat-C1/C2
Sensor Name	SWIR-2	SWIR-2
Band(s) / Beam Mode(s) and Polarization	SWIR 1635-1675 nm, multiple bands in a proprietary configuration, unpolarised	SWIR 1635-1675 nm, multiple bands in a proprietary configuration, unpolarised
Spatial Resolution	<30 m	<30 m
Geometric Corrections Performed	Radial distortion, perspective projection	Radial distortion, perspective projection
Radiometric Corrections Performed	Detector pixel response, ghosting, spectral response, atmospheric correction including trace gas modelling and surface reflectance	Detector pixel response, ghosting, spectral response, atmospheric correction including trace gas modelling and surface reflectance
Data Format(s): Default and/or Options	GeoTIFF (16-bit); optional GeoTIFF (32-bit or 64-bit floating point)	PNG (optional PDF) plus A.2.0 products (GeoTIFF by default)
Time Period Covered by the Catalogue Data	September 2020 to Present	September 2020 to Present
Species Measured	CH_4	CH_4
Measurement Period	Instantaneous (Single Scene)	Instantaneous (Single Scene)

Table 4: Summary of GHGSat-C1 and GHGSat-C2 Abundance and Concentration Products

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Note: For products A.2 and A.3, GHGSat differentiates between complex source and point source. A point source is typically a single physical feature (e.g. an industrial chimney/stack, or group of stacks within a few hundred metres 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.

4.3 Emission Rate Product (Level 4)

Emission rates from targeted sources are estimated using abundance data from a single satellite pass and applying dispersion modelling techniques. The delivered products include (i) a CSV file giving the emission rate estimates, their uncertainties and key dispersion parameters for each observation, and (ii) the Product A.2.0 abundance datasets (see Table 4) used for the emission estimates.

Property	Product D.1.0_CH4
Product Name	***Emission Rate – CH4***
Satellite	GHGSat-C1/C2
Sensor Name	SWIR-2
Spatial Resolution	<30 m
Product Description	Emission rates estimated using the abundance dataset from each scene and applying source rate retrieval techniques
Projection Information (if applicable)	Per Product A.2.0 (see Table 4)
Data Format(s): Default and/or Options	PDF + CSV + Product A.2.0 formats
Species Measured	CH_4
Measurement Period	Instantaneous (Single Scene)

Table 5: Optional Products – Emissions Rates

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5 PRODUCT LICENSING

GHGSat licenses the GHGSat-C1 and GHGSat-C2 products described in this document in according with an end-user license agreement (EULA) provided via ESA EarthNet.

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6 PRODUCT NAMING

The file naming convention consists of four subfields separated by underscores and keys as follows:

*SensorAbbr*_SON*SupplierOrderNumber*_CON*ClientOrderNumber*_COLN*ClientOrderLineNumber*

Where:

- *SensorAbbr* is the sensor abbreviation.
- *SupplierOrderNumber* is the Offeror order number, starting with SON. By default, the number is the Observation ID (composed of 7 alphanumeric characters) and the processing date (YYMMDD).
- *ClientOrderNumber* is the Identified User requisition order number, starting with CON.
- *ClientOrderLineNumber* is the Identified User order line/item number, starting with COLN.

Note: All fields are in upper case.

Example: Delivery of GHGSat-C1 Abundance Dataset

SensorAbbr: GC1SW2

SupplierOrderNumber: ID12345YYMMDD

ClientOrderNumber: 0017000001

ClientOrderLineNumber: 01

Product compressed (zip) file name: GC1SW2_SONID12345YYMMDD_CON0017000001_COLN01.zip

Once unzipped, the folder <GC1SW2_SONID12345YYMMDD_CON001700001_COLN01> will contain the image or data files, the metadata file, a browse image and other files as described under Product Delivery Package in Section 7.1 of this document.

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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
	Metadata for additional description of the imagery / data
Additional Information	Any associated processing files and documentation to help the user to understand the product and facilitate data use.

Table 6: GHGSat Product Delivery Package

7.2 Delivery Methods and File Format

GHGSat is delivering products via is online Datamaster system until mid-2021, at which time it will transition to an ESRI platform. The platform will provide visibility to GHGSat's public catalogue and access to project-specific observation products and data. Each ESA project will be provided unique password protected access. GHGSat will provide email notification of product and data delivery to designated user points-of-contact.

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8 METADATA

An ASCII file following the KEY=VALUE conventions and encoding metadata is provided.

Properties	Required (R) or Desirable (D)	Metadata Format
Metadata Version	R	**METADATA_VERSION**
Satellite or Constellation and Sensor Name(s)	R	Satellite,Sensor (e.g. "GHGSat-C1_2021,SWIR-2") **SATELLITE** **SENSORS**
Ordering and Contact Information ☐File Base Name ☐Sensor ID ☐Supplier Order Number ☐Client Order Number ☐Product ID ☐Technical Authority Email ☐Technical Authority Website URL ☐Phone Number of Technical Authority	D	**BASE_NAME** **ORDER_SENSORABBR** **ORDER_SUPPLIER** **ORDER_CLIENT** **ORDER_PRODUCT** **TECH_AUTH_EMAIL** **TECH_AUTH_URL** **TECH_AUTH_PHONE**
File Origin and License: ☐File source ☐Source Website URL License Class ☐License Filename ☐License Language (en-English) ☐License File Size ☐License Version ☐SHA-256 License Key	D	**ORIGINATOR** **ORIGINATOR_URL** **LICENSE_CLASS** **LICENSE_FILE** **LICENSE_LANGUAGE** **LICENSE_SIZE** **LICENSE_VERSION** **LICENSE_SHA256**
Product Type: ☐Number of Product Types ☐PRODUCT_TYPE_X = Product Type ☐PRODUCT_TYPE_X_LAYERS = Layers Associated to Product Type ☐PRODUCT_TYPE_ID (i.e.: A20ADCH4)	R	**PRODUCT_TYPES** **PRODUCT_TYPE_X** **PRODUCT_TYPE_X_ID**
Browse Image (thumbnail): A reduced resolution product normally associated with catalogue browse functions and supplied with the product delivery package. A world file is included whose name is the base name followed by _BRW. Please use the projection information provided in the metadata to use the world file.	R	PNG file, not exceeding 64 kB **BROWSE_ROWS** **BROWSE_COLUMNS** **BROWSE_FILETYPE** **BROWSE_SIZE** **BROWSE_PNG_SUFFIX** **BROWSE_WLD_SUFFIX**
Acquisition Time (UTC) (Start/Stop)	R	GPS-derived UTC encoded as real seconds since Unix epoch (1970-01-01); ISO-8601 time strings **START_TIME_UNIX** **STOP_TIME_UNIX** **START_TIME_ISO8601** **STOP_TIME_ISO8601**
Geometry: Sensor Viewing / Incidence Angle ☐Sun Zenith ☐Sun Azimuth ☐Line of Sight Zenith ☐Line of Sight Azimuth ☐Satellite Height (m)	R	Azimuth and zenith angles for sensor and sun at central pixel, decimal degrees. **SUN_ZEN** **SUN_AZI** **LOS_ZEN** **LOS_AZI** **SATELLITE_HEIGHT**
Image corner coordinates including upper	R	Bounding box in geodetic latitude degrees

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Properties	Required (R) or Desirable (D)	Metadata Format
left, lower left, upper right, lower right.		north, longitude degrees east, in signed decimal degrees, range -90 to +90, -180 to +180; Four image corner coordinate pairs expressed in image UTM grid, comma-separated, Easting, Northing. **LATITUDE_MIN_DEG** **LATITUDE_MAX_DEG** **LONGITUDE_MIN_DEG** **LONGITUDE_MAX_DEG** **CORNER_UL_UTM** **CORNER_UR_UTM** **CORNER_LL_UTM** **CORNER_LR_UTM**
Dimensions Number of Map Number of Layers Number of Pixels / Samples and Number of Lines	R	Map indicates the number of maps associated with the observation. Layers indicate the number of GeoTIFF associated with the observation. Rows and columns show the number of pixels in a given row or column. **MAPS** **LAYERS** **ROWS** **COLUMNS**
Data Processing Level	R	**LEVEL** (Highest processing level)
Additional data processing information, including: List of processing levels, processor name and version, and other processing relevant information	D	**PROCESSING_GROUP_x_LEVELS** **PROCESSING_GROUP_x_PROCESSSOR** **OBSERVATION_ID**
Spatial Resolution / Pixel Spacing	R	Raster image space to model space transformation matrix **TRANSFORMATION_abcd** **TRANSFORMATION_efgh** **TRANSFORMATION_ijkl** **TRANSFORMATION_mnop**
Projection information, including: map projection, UTM zone, ellipsoid, datum Example: PROJECTION=: WGS 84/ UTM 18 N PROJECTION_WKT=PROJCS["WGS 84 / UTM zone 18N",GEOGCS["WGS 84",DATUM["WGS_1984",SPHEROID["WGS 84",6378137,298.257223563,AUTHORITY["EPSG","7030"]],AUTHORITY["EPSG","6326"]],PRIMEM["Greenwich",0],UNIT["degree",0.0174532925199433],AUTHORITY["EPSG","4326"]],PROJECTION["Transverse_Mercator"],PARAMETER["latitude_of_origin",0],PARAMETER["central_meridian",-75],PARAMETER["scale_factor",0.9996],PARAMETER["false_easting",500000],PARAMETER["false_northing",0],UNIT["metre",1,AUTHORITY["EPSG","9001"]],AUTHORITY["EPSG","32618"]]	R	**PROJECTION** **PROJECTION_WKT**

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Properties	Required (R) or Desirable (D)	Metadata Format
Unit conversions	D	Conversion factors for converting from ppb to mol/m^2 and vice-versa **CH4_MOLM2_TO_PBB_FACTOR** **CH4_PPB_TO_MOLM2_FACTOR**
Details information on each layer: ☐LAYERX_NAME: Surface Reflectance or CH4 Abundance Dataset or Quality Flags ☐LAYERX_TYPE: Data type ☐LAYERX_LAMBDA0 and LAYERX_LAMBDA1: 95% spectral band pass limits (two wavelengths in nanometers) provided as part of layer details. ☐LAYERX_QUANTITY: Short description of layer ☐LAYERX_UNITS: Units ☐LAYERX_MIN: Minimum value in layer units ☐LAYERX_MAX: Maximum value in layer ☐LAYERX_FORMATS: Layer data formats available. Usually only 'TIFF'. For real layers given as non-floating-point formats, conversion coefficients are provided in LAYERX_ADD and LAYERX_MUL fields. For example, if LAYER3_MUL=30E-6 and LAYER3_ADD=0.5 and if the pixel value in the #layer is the integer N the corresponding real value would be N * LAYER3_MUL + LAYER3_ADD. For the quality flags layer: LAYERX_FLAGS indicates the pixel quality (Flag Value , Quality). For example: (1,'Good'), (2, 'No Data'), (3, 'Bad fit') LAYERX_MEAN_BACKGROUND_LEVEL: Mean background column density level	R	GEOTIFF; Optional HDF4, IEEE 754 floating point array or bitmap file (TIFF, PNG, PNM) with sidecar world file or ENVI header **LAYERX_NAME** **LAYERX_TYPE** **LAYERX_LAMBDA0** **LAYERX_LAMBDA1** **LAYERX_QUANTITY** **LAYERX_SPECIES** **LAYERX_UNITS** **LAYERX_MIN** **LAYERX_MAX** **LAYERX_FORMATS** **LAYERX_ADD** **LAYERX_MUL** **LAYERX_FLAGS** **LAYERX_MEAN_BACKGROUND_LEVEL** **LAYERX_PRODUCT_TYPE_ID**
Details information on Map Product. For CH_4 A.3.0_CH4	D	**MAPx_NAME** **MAPx_FORMATS** **MAPx_PNG_SUFFIX** **MAPx_UNITS** **MAPx_SPECIES** **MAPx_RELATED_LAYERS** **MAPx_LAYER_BACKGROUND** **MAPx_LAYER_FOREGROUND** **MAPx_PRODUCT_TYPE_ID** **MAPx_CONVERSION_FACTOR** **MAPx_CONVERSION_FACTOR_UNITS**

Table 7: GHGSat Metadata Format

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