ICEYE

LEVEL 1 PRODUCT FORMAT SPECIFICATION DOCUMENT

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CHANGELOG

DOCUMENT ISSUE DATE	LEVEL 1 FORMAT SPEC	ICEYE SAR PROCESSOR VERSION	COMMENTS
2020-06-11	V2.1	V1.1.2	Added metadata for tropo_range_delay Removed N/A line from GRD XML (table 12)
2020-05-26	V2.0	V1.1.1	Added various metadata items Moved metadata to appendices Included RPC definitions
2020-02-01	V1.0	V1.0	First compliant version

LIST OF ACRONYMS

ASCII	American Standard Code for Information Interchange
BSD	Berkeley Software Distribution
CF	Calibration Factor
C_N	Coefficient '*n*' in a polynomial
DC	Doppler Centroid
DN	Digital Number
ECEF	Earth-Centered, Earth-Fixed
GR	Ground Range
GRD	Ground Range Detected
GRSR	Ground Range to Slant Range conversion
HDF	Hierarchical Data Format
IGR_0	Incidence Angle Ground Range Origin
KML	Keyhole Markup Language
PNG	Portal Network Graphics
PRF	Pulse Repetition Frequency
RPC	Rational Polynomial Coefficient
SR	Slant Range
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
UTC	Coordinated Universal Time
VV	Polarization (Vertical transmitted and Vertical received)
WGS84	World Geodetic System (1984)
XML	eXtensible Markup Language

LIST OF SYMBOLS

SYMBOL	DESCRIPTION
β_0	Radar Brightness
f_{sr}	Range Sampling Rate
θ	Incidence angle on ground calculated using the ellipsoidal Earth model
σ_0	Radar Backscattering coefficient
t	Range (fast) time
P	Normalized geodetic latitude
L	Normalized geodetic longitude
H	Normalized geodetic height
r_n	Normalized row
c_n	Normalized column

SAR GLOSSARY

▶ SAR GLOSSARY

AZIMUTH	Direction aligned with the relative spaceborne platform velocity vector.
DETECTION	Processing step in which the phase information is removed and only the signal amplitude is preserved. Normally the detection uses a magnitude squared method and has units of voltage square per pixel.
FOCUSING	Data processing finalized to focus the SAR image in range and azimuth through bidimensional signal compression.
GROUND RANGE	Projection of the slant range into the ground.
INCIDENCE ANGLE	Local incidence angle on ground calculated using the ellipsoidal Earth model.
LOOKS	Image obtained using only part of the spectrum to focus the image (subaperture). It can be done in range and in azimuth, and normally is used to reduce the speckle noise from SAR images through incoherent sum (multi-look process).
RANGE	Direction orthogonal to the satellite velocity.
SLANT RANGE VECTOR	Line-Of-Sight distance between the antenna and the target on ground.
SLANT RANGE PLANE	Plane containing the relative sensor velocity vector and the slant range vector for a given target.

1. INTRODUCTION

▶ INTRODUCTION

ICEYE's SAR satellite constellation provides commercial access to timely and reliable fine resolution Synthetic Aperture Radar Earth observation data. Data from the ICEYE constellation is available in various formats and this document is intended to describe the specifications for ICEYE's basic SAR Level 1 products.

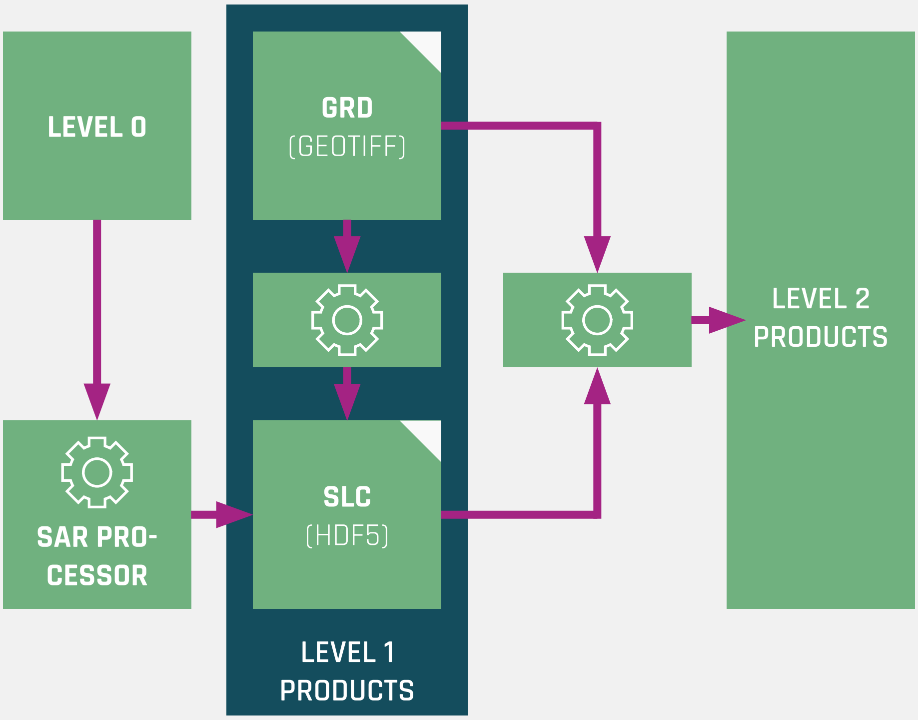

Figure 1. ICEYE SAR Product Levels

ICEYE is constantly evolving its product line. Level 1 products are likely to change in the future and those changes will be reflected in future updates of this document. A key part of this process is the valuable customer feedback we receive. Questions and/or comments on this documentation or how to order an ICEYE product should be directed to our Customer Success team at customer@iceye.com

INTRODUCTION

1.1 SCOPE

This document defines the format of Level 1 product components for imagery products generated from the ICEYE SAR constellation. Level 1 products include georeferenced satellite path oriented products, that can be further orthorectified using specialized SAR software tools such as the ESA Sentinel Application Platform Toolbox SNAP Toolbox[1].

1.2 DOCUMENT STRUCTURE

This document is designed to provide detailed information on the format and specification of ICEYE level 1 products. It starts in section 2 with an overview of the rationale behind ICEYE's level 1 product offerings and a description of the file formats used. This is followed in section 3 with a description of the delivery package that ICEYE uses. Section 4 then describes the image products themselves. In section 5, technical descriptions are provided for the key metadata components of the products. Finally section 6 lets the reader know how to contact ICEYE and section 7 provides references and further reading.

It could be argued however that the most useful part of this document are the appendices where the precise metadata for each image product is described in table form together with useful information to allow a user to get the most from their ICEYE imagery. These have been kept in product-related sections and alphabetized in order to provide an easy and consumable reference.

2. LEVEL 1 SAR PRODUCT FORMAT RATIONALE

Earth Observation Products are available in varying processing levels. The levels are defined by the Committee for Earth Observation Satellites[2] as :

- **RAW Data** - Data in their original packets, as received from a satellite.
- **Level 0** - Reconstructed unprocessed instrument data at full space time resolution with all available supplemental information to be used in subsequent processing (e.g., ephemeris, health and safety) appended.
- **Level 1** - Unpacked, reformatted level 0 data, with all supplemental information to be used in subsequent processing appended. Optional radiometric and geometric correction applied to produce parameters in physical units. Data generally presented as full time/space resolution. A wide variety of sub level products are possible.
- **Level 2** - Retrieved environmental variables (e.g., ocean wave height, soil moisture, ice concentration) at the same resolution and location as the level 1 source data.
- **Level 3** - Data or retrieved environmental variables which have been spatially and/or temporally re-sampled (i.e., derived from level 1 or 2 products). Such re-sampling may include averaging and compositing.
- **Level 4** - Model output or results from analyses of lower level data (i.e., variables that are not directly measured by the instruments, but are derived from these measurements).

ICEYE provides its SAR imagery products as CEOS Level 1. These are satellite path oriented datasets and can be ordered either from archive (previously collected imagery) or as future acquisitions by contacting ICEYE's Customer Success Specialists. Products are geo-coded and radiometrically corrected and are described in the ICEYE Product Guide[3]. ICEYE's main focus is currently on the development of high integrity level 1 products with some level 2 products being obtained through second party applications. This will gradually evolve over the next year as processing modes and calibration metrics evolve with new level 2 products being provided by the ICEYE processing architecture.

A basic ICEYE product is represented by a set of SAR image binary data, corresponding image metadata and delivered as a singular product package. Products are characterized by the payload configuration (such as imaging mode and look direction) used by the respective satellite, as well as the level of processing that has been applied to the SAR scene. With respect to the data geometric projection and representation, Level 1 products are differentiated into two primary product types: geo-referenced Single Look Complex (SLC) and Ground Range Detected (GRD) scenes. SAR image binary data, delivered as digital numbers or quadrature components, can be converted to radar brightness β_0 using the annotated calibration factor, or further radiometrically calibrated.

2.1 LEVEL-1 SINGLE LOOK COMPLEX

Single Look Complex (SLC) products are images derived from the focused SAR signal. Scenes are stored in the satellite image acquisition geometry. The image coordinate system is centred on the zero-Doppler (time of closest approach) SAR coordinates and are arranged in the slant-range-by-azimuth imaging plane. The pixels are spaced equidistant in azimuth (according to the inverse of the pulse repetition frequency) and in slant range (according to the range sampling frequency). Each image pixel is represented by a complex magnitude value (with in-phase I and quadrature Q components) and therefore, contains both amplitude and phase information. Each image pixel is processed to zero Doppler coordinates in the range direction, i.e. perpendicular to the ground track[4].

SLC products are most suitable for advanced users that intend to use phase information, primarily in interferometric applications, or prefer lower level processing in order to implement their own processing chains. The SLC product has no radiometric artefacts induced by spatial resampling or geocoding, and can be orthorectified using both commercial and free specialized SAR software tools such as the European Space Agency (ESA) Sentinel Application Platform (SNAP)[5].

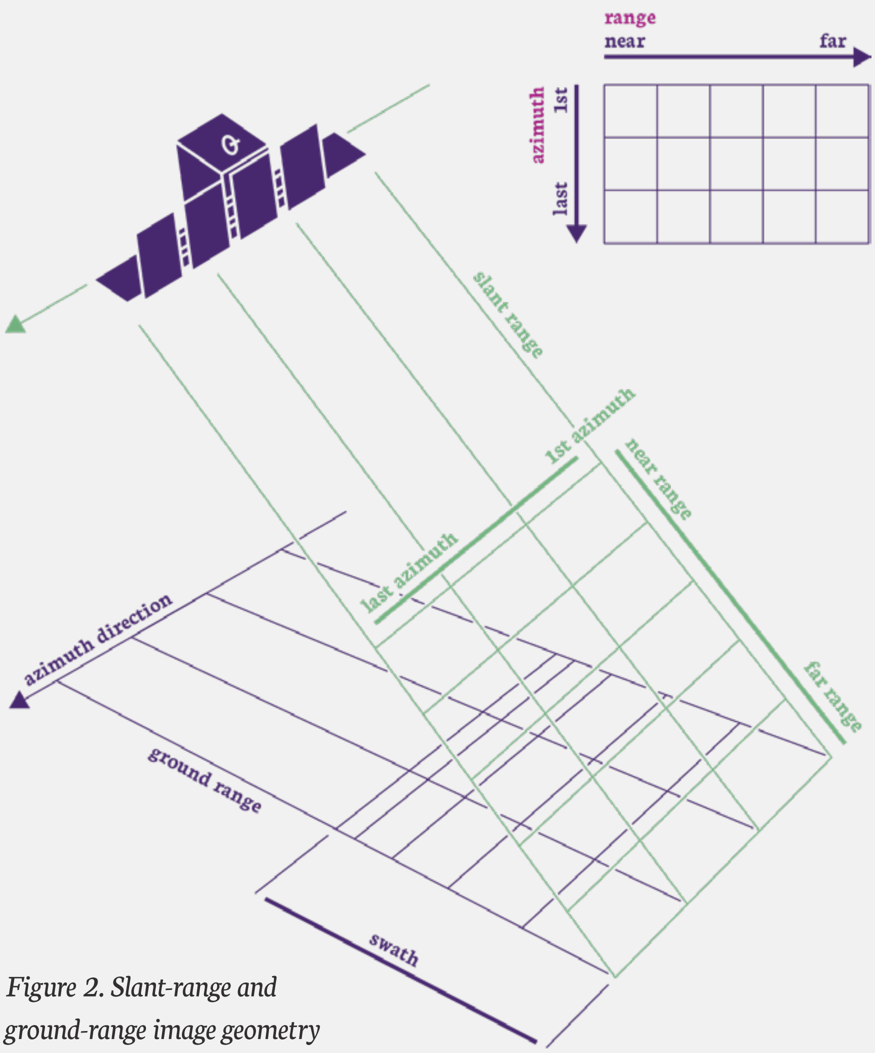

Figure 2. Slant-range and ground-range image geometry

2.2 LEVEL-1 GROUND RANGE DETECTED

Ground Range Detected (GRD) products represent focused SAR data that has been detected and (usually) multi-look processed and projected to the ground plane using an Earth ellipsoid model. The image coordinates are oriented along the flight direction and ground range. The pixel spacing is equidistant in azimuth and in ground range. Ground range coordinates are the slant range coordinates projected onto the ellipsoid of the Earth. For the slant to ground range projection the WGS84 (EGM96) ellipsoid and an averaged fixed value of terrain height is used, annotated in the metadata. Pixel values represent detected amplitude. Phase information is lost. The resulting product has approximately circular spatial resolution and square pixel spacing.

Additionally, an incidence angle dependence in range, calculated using the WGS84 ellipsoidal Earth model has been applied to facilitate the conversion of radar brightness to backscatter intensity. This is explained in more detail in Section 5

The advantage of this product is that no image rotation to a map coordinate system has been performed and interpolation artefacts are thus avoided. This product is useful for applications that only require amplitude information and if geocoding or orthorectification is to be applied by the user, or for applications where geocoding is not required.

To assist users that require geocoded imagery with minimal interpolation artefacts, ICEYE GRD products are tagged with ground control points (GCP) and rational polynomial coefficients (RPC's). These allow precise geospatial exploitation using freely available tools such as QGIS[6] or GDAL[7].

2.3 FILE FORMAT

Hierarchical Data Format (HDF)[8] is the primary means for storing the image metadata and binary image data of SLC products. The format libraries and associated tools are available under a liberal, BSD-like license for general use. HDF is widely supported by both commercial and non-commercial image processing software and software development platforms.

For GRD products, the format of choice is GeoTIFF. This enables a quick and professional assessment of the SAR imagery using common GIS tools, and a compact storage of both image metadata and the detected amplitude of the image data. Image orthorectification still needs to be performed using specialized SAR software for precise geospatial mensuration.

In order to simplify access to product metadata, information about the product is gathered in an auxiliary XML file. The chosen format is similar to those implemented for TerraSAR-X/TanDEM-X and RADARSAT-2 missions. Each binary image product has its own XML metadata file.

Although ICEYE imagery can be collected in a variety of imaging and beam modes, the annotated metadata contains all the required information for the delivered product and is designed to be as uniform as possible across all the product types.

3. PRODUCT DELIVERY PACKAGE

In this section the package directory structure and file naming conventions for Level 1 products are described.

3.1 PACKAGE STRUCTURE AND FILE NAMES

The Level 1 Product package consists of a set of files with binary image data and metadata. The package is combined into a single zipped file for easy delivery and archiving. The structure of the delivery package for the Level 1 Products is shown in Figure 3 and consists of:

- A GRD image and its auxiliary XML metadata
- A QUICKLOOK image and its auxiliary KML file
- A SLC image and its auxiliary XML metadata
- A thumbnail image in a PNG format with KML file

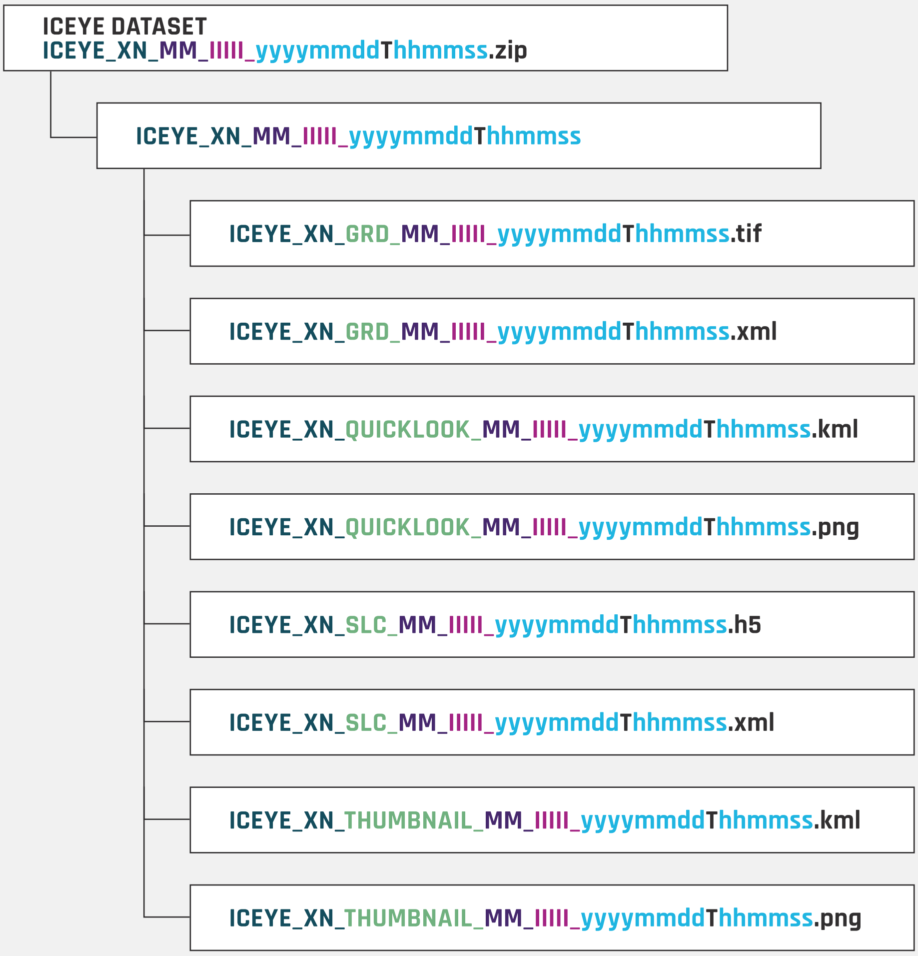

Figure 3. Structure of the delivery package for ICEYE Level 1 Products

▶ PRODUCT DELIVERY PACKAGE

3.2 FILE NAMING CONVENTIONS

Product file naming is designed to facilitate understanding of the product processing level and key properties at an early stage, without the need to analyze product metadata. The product filename components are shown in Figure 4.

In Figure 4 the Product ID is shown as a unique identifier of the acquired scene and is assigned during scene ordering and acquisition.

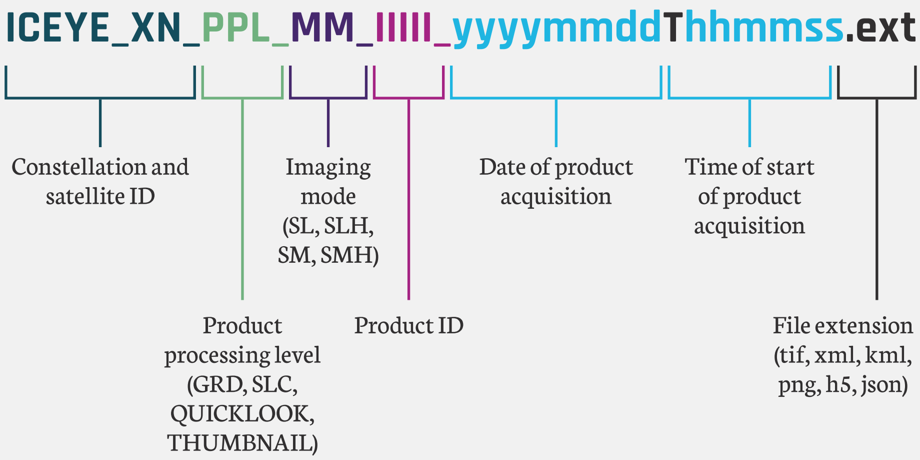

Figure 4. Level 1 Product filename components

PRODUCT DELIVERY PACKAGE

A description of the constituent elements are explained in more detail in Table 1

CONSTITUENT	NAME	VALUE	NOTES
ICEYE_	constellation	ICEYE_	fixed
XN_	sensor	X2/X4/X5	specific sensor that has acquired the scene
PPL_	product processing level	SLC/GRD	variant of processing level
IM_	imaging mode	SM/SMH/SL/SLH	stripmap, stripmap-high, spotlight, spotlight-high
PRID_	product id	eg. 6403	data take ID
FFFFFF	UTC start date	eg. 20190211	YYYYMMDD format
TGGGGGG	UTC start time	eg. T131415	Thhmmss format

Table 1. Product filename components.
Example: ICEYE_X2_SLC_SL_26131_20200409T084252

4. SAR LEVEL 1 PRODUCT DESCRIPTIONS

ICEYE's SAR image data presently consists of one polarimetric channel (VV) stored in a binary data matrix. In this section the storage format of the image products will be described.

4.1 SINGLE LOOK COMPLEX (SLC) IMAGE PRODUCT

Single Look Complex (SLC) data products are stored as binary matrices in an HDF5 file [8]. Real and imaginary components are stored separately, using either signed 16 bit integers or IEEE-754 single precision 3-bit floating point format (the version used is annotated in the metadata). It is assumed that all pixels are valid, unless marked with a NaN (Not a Number) value. The structure of the binary data is shown in Figure 5. Each row of the matrix is a single range line of the image with increasing range preceding from lower indices to higher indices (left to right in Figure 5). Early row indices in the matrix correspond to early pulses and later rows correspond to later pulses (top to bottom in Figure 5). It is important to recognise that image viewing software needs to take into account the matrix configuration as viewing the matrix as it is stored may result in the image being reflected in either dimension depending on right/left looking and ascending/descending.

NEAR RANGE — RANGE DIRECTION — **FAR RANGE**

FIRST ROW — AZIMUTH DIRECTION — **LAST ROW**

[A1,R1]	[A1,R2]	[A1,R3]	[A1,R4]	...	[A1,RM]
[A2,R1]	[A2,R2]	[A2,R3]	[A2,R4]	...	[A2,RM]
[A3,R1]	[A3,R2]	[A3,R3]	[A3,R4]	...	[A3,RM]
[A4,R1]	[A4,R2]	[A4,R3]	[A4,R4]	...	[A4,RM]
...	...	...	...	...	...
[AN,R1]	[AN,R2]	[AN,R3]	[AN,R4]	...	[AN,RM]

Figure 5. Complex SAR scene geometry in slant range

The SLC HDF5 container contains metadata associated with the collection in its header structure. The metadata is described in Appendix A . HDF and metadata tags can easily be found using a Python interpreter and the commands :

```
import h5py
f = h5py.File("<filename.h5>")
for key in f.keys():
    print(f[key])
```

4.1.1 SLC XML

To assist in easier exploitation, ICEYE also provides the metadata in an auxiliary XML file. The SLC-XML metadata composition can be found in Appendix B

4.2 GROUND RANGE DETECTED (GRD) IMAGE PRODUCT

The image data layer DNGRD of detected SAR products are stored in a GeoTIFF file format using unsigned 16 bit representation along with a combination of commonly used and specifically defined GeoTIFF tags. GeoTiff files are readable with standard image processing and GIS software tools.

GRD products are located in the ground-range-by-azimuth surface, with image coordinates oriented along ground range and ground track directions. The GRD product is a detected product with square pixel spacing. Different imaging modes and different incidence angles may have a native sample spacing in the slant range that is not square and so square sample spacing and a circular impulse response function in the ground plane is achieved either by varying the transmitted bandwidth or by applying multi-looking during the slant to ground transformation and detection process.

Typically, the detection is performed as

$$|DN_{SLC}|^2 = (I^2 + Q^2)$$

with I^2 and Q^2 representing the real and imaginary amplitude of the complex backscatter.

▶ SAR LEVEL 1 PRODUCT DESCRIPTIONS

For GRD scenes, a conversion to sigma-naught has been already applied using an incidence angle that is calculated from the ellipsoidal Earth model:

$$|DN_{GRD}|^2 = |DN_{SLC}|^2 \cdot sin(\theta)$$

ICEYE level 1 products are calibrated using the Amazon and Congo forests for radiometric and beam calibration and using point target calibration sites for impulse response and geolocation calibration. The conversion to radar brightness (β_0) values are provided through the application of a calibration factor (CF) annotated within the product metadata:

$$\beta_0 = CF \frac{|DN_{GRD}|^2}{sin(\theta)}$$

Gamma-naught values can be obtained using the beta-naught values and a local DEM.

To assist in viewing analysis and projection, all GRD products are projected onto the WGS84 Reference Ellipsoid. Ellipsoid parameters and metadata tags can easily be found using the command :

```
gdalinfo <geotiff_filename.tif>
```

The GRD metadata elements can be found in Appendix C

ELLIPSOID REFERENCE	SEMI MAJOR AXIS	SEMI MINOR AXIS	INVERSE FLATTENING
WGS84	6 378 137.0 m	≈ 6 356 752.314 245 m	298.257 223 563

Table 2. ICEYE GRD Product Datum

4.2.1 GRD XML

To assist in easier exploitation, ICEYE also provides the GRD metadata in an auxiliary XML file. The GRD-XML metadata composition can be found in Appendix D.

4.3 QUICKLOOK

ICEYE also provides a QUICKLOOK product to rapidly look at an image without needing to use analytical tools. The QUICKLOOK product comprises a PNG graphic and a KML file. The PNG file is a digital raster of detected values arranged in the same format described in Figure 5. As a result, the file may be flipped in either the vertical or horizontal direction if viewed on its own. For best results the KML file should be viewed using Google Earth® or a KML viewer. This will then load the PNG file and provide the correct geographic representation of the QUICKLOOK product.

4.4 THUMBNAIL

For convenience and to facilitate archive storage, a thumbnail product is also provided in the dataset. This consists of a small PNG image and a KML file describing the image corner coordinates. As with the QUICKLOOK product, it is recommended that the KML file be used to view the image if the correct geographic orientation is desired.

5. PRODUCT COMPONENT DESCRIPTIONS

ICEYE Products provide many parameters that allow a user to increase the amount of information that they can extract from an imaging operation. These will now be described.

5.1 CALIBRATION PARAMETERS

The calibration factor CF is used to derive the radar brightness β_0 from the binary image pixel values of the SLC product. The expression for the radar brightness takes the form:

$$\beta_0 = CF \cdot |DN_{SLC}|^2 \, , \, \beta_{0dB} = 10 \cdot log10(\beta_0)$$

FIELD NAME	TYPE	UNIT	DESCRIPTION	VALUE EXAMPLE
calibration_factor	float64	Number	Factor to be applied to calibrate detected products to absolute brightness intensity	0.000012341123

Table 3. Calibration Factor parameter found in the product metadata

For GRD scenes, a conversion to sigma-naught has already been applied using the incidence angle calculated from the ellipsoid model. This simplifies the calculation of the radar backscatter to:

$$\sigma_0 = CF \cdot |DN_{GRD}|^2$$

$$\sigma_{0dB} = 10 \cdot log10(\sigma_0)$$

$$|DN_{GRD}|^2 = |DN_{SLC}|^2 \cdot sin(\theta)$$

If the processing of beta-naught is required for further orthorectification to sigma-naught or gamma-naught values using a local DEM, then the conversion to radar brightness can be performed using the incidence angle information annotated in the metadata (Table 14). The incidence angle value for each ground range location can be calculated as:

$$\theta_j = \sum_{k=0}^{p-1} C_k \cdot (IGR_0 + (j - 1) \cdot rs)^2 \, , \, j = [1, n]$$

where θ_j is incidence angle for j-th pixel in ground range, IGR_0 is the incidence angle ground range origin, and rs is the ground range spacing.

▶ PRODUCT COMPONENT DESCRIPTIONS

5.2 DOPPLER CENTROID DETERMINATION

In this section the processor and product-configuration parameters are provided as well as parameters derived from the data during screening and processing. Doppler Centroid (DC) coefficient estimates are provided every second from the start of image acquisition. For each azimuth location, the DC dependence in range is described using a polynomial function. The polynomial is valid from the near to the far range of the scene. The DC coefficients can be obtained by fitting the DC dependence in range from time as:

$$DC(t) = C_0(t - t_{ref})^0 + C_1(t - t_{ref})^1 + C_2(t - t_{ref})^2 + C_3(t - t_{ref})^3$$

where the reference point in time t_{ref} corresponds to the mid-range time, and time varies between t_{min} and t_{max} corresponding to near range (first pixel time) and far range, respectively.

The mid- range time is calculated as:

$$t_{ref} = (t_{min} + t_{max}) / 2 = t_{min} + n_{rs} / (2 \cdot f_{sr})$$

where n_{rs} is the number of range samples, and f_{sr} is the range sampling rate.

The *DC* coefficient information, for each *DC* estimate, follows.

5.3 GROUND RANGE TO SLANT RANGE CONVERSION

For GRD products, the ground range to slant range (GRSR) conversion can be performed using the GRSR polynomial with coefficients stored in the annotated data. Once applied, the slant range location of a specific pixel in the ground range can be calculated as:

$$SR_j = \sum_{k=0}^{p-1} C_k \cdot (GR_0 + (j - 1) \cdot rs)^k , j = [1, n]$$

where, SR_j and GR_j are the slant and ground range locations for the j-th pixel, respectively; GR_0 is the ground range origin, and rs is ground range spacing.

PRODUCT COMPONENT DESCRIPTIONS

5.4 RATIONAL POLYNOMIAL COEFFICIENTS (RPC)

To help with the determination of precise pixel locations, a RPC model has been implemented into the output product files. The model is described in OSGeo[9] which extends the work for the National Imagery Transmission Format (NITF) [10] to GeoTIFFs. For completeness, the translation of latitude and longitude to image pixel coordinates is described here.

The geometric sensor model describing the physical relationship between image coordinates and ground coordinates is known as a Rigorous Projection Model. A Rigorous Projection Model expresses the mapping of the image space coordinates of rows and columns (r,c) onto the object space reference surface geodetic coordinates (φ, λ, h).

The definition of RPC values was first described in STDI-0002 2.1 [10] and specifically sections 3.2.4 (the mathematical description) and section 8.3.12 that describes how RPC parameters could be stored electronically.

The approximation used in ICEYE products is a set of rational polynomials that describe the normalized row and column values, (r_n, c_n), as a function of normalized geodetic latitude, longitude, and height, (P, L, H), given a set of normalized polynomial coefficients (`LINE_NUM_COEF_n`, `LINE_DEN_COEF_n`, `SAMP_NUM_COEF_n`, `SAMP_DEN_COEF_n`). Normalized values, rather than actual values are used in order to minimize the introduction of errors during the calculations. The transformation between row and column values (r,c), and normalized row and column values (r_n, c_n), and between the geodetic latitude, longitude, and height (φ, λ, h), and normalized geodetic latitude, longitude, and height (P, L, H), is defined by a set of normalizing translations (offsets) and scales that ensure all values are contained within the range -1 to +1.

The normalization of these parameters is given in Table 4.

▶ PRODUCT COMPONENT DESCRIPTIONS

NORMALISED	DEFINITION
P	(Latitude - LAT _ OFF) / LAT _ SCALE
L	(Longitude - LONG _ OFF) / LONG _ SCALE
H	(Height - HEIGHT _ OFF) / HEIGHT _ SCALE
r_n	(Row - LINE _ OFF) / LINE _ SCALE
c_n	(Column - SAMP _ OFF) / SAMP _ SCALE

Table 4. Normalization of RPC parameters

The GeoTIFF encoding of the RPC data in ICEYE data products is provided as a structure of 14 parameters described in Table 5.

The equation to calculate the row and column number from the RPC values is given by:

$$r_n = \frac{\sum_{i=1}^{20} LINE\_NUM\_COEF_i \cdot \rho_i(P,L,H)}{\sum_{i=1}^{20} LINE\_DEN\_COEF_i \cdot \rho_i(P,L,H)}$$

$$c_n = \frac{\sum SAMP\_NUM\_COEF_i \cdot \rho_i(P,L,H)}{\sum SAMP\_DEN\_COEF_i \cdot \rho_i(P,L,H)}$$

PRODUCT COMPONENT DESCRIPTIONS

Where the rational polynomial numerators and denominators are each a 20-point cubic polynomial function of the form:

$$\sum_{i=1}^{20} C_i \cdot \rho_i(P,L,H) =$$

$$\begin{array}{llll} C_1 & + C_6LH & + C_{11}PLH & + C_{16}P^3 \\ + C_2L & + C_7PH & + C_{12}L^3 & + C_{17}PH^2 \\ + C_3P & + C_8L^2 & + C_{13}LP^2 & + C_{18}L^2H \\ + C_4H & + C_9P^2 & + C_{14}LH^2 & + C_{19}P^2H \\ + C_5LP & + C_{10}H^2 & + C_{15}L^2P & + C_{20}H^3 \end{array}$$

Where coefficients $C_1 \ldots C_{20}$ represent the vector coefficients provided in the product metadata : `LINE_NUM_COEF_n, LINE_DEN_COEF_n, SAMP_NUM_COEF_n, SAMP_DEN_COEF_n`

The image coordinates are in units of pixels. The ground coordinates are latitude and longitude in units of decimal degrees and the height above ellipsoid in units of meters. The ground coordinates are referenced to WGS84.

NAME	DESCRIPTION	VALUE RANGE	UNITS
LINE _ OFF	Line Offset	>= 0	pixels
SAMP _ OFF	Sample Offset	>= 0	pixels
LAT _ OFF	Geodetic Latitude Offset	-90 to +90	degrees
LONG _ OFF	Geodetic Longitude Offset	-180 to +180	degrees
HEIGHT _ OFF	Geodetic Height Offset	unlimited	meters
LINE _ SCALE	Line Scale	> 0	pixels
SAMP _ SCALE	Sample Scale	> 0	pixels
LAT _ SCALE	Geodetic Latitude Scale	0 < LAT_SCALE <= 90	degrees
LONG _ SCALE	Geodetic Longitude Scale	0 < LONG_SCALE <= 180	degrees
HEIGHT _ SCALE	Geodetic Height Scale	HEIGHT_SCALE > 0	meters
LINE _ NUM _ COEFF (1-20)	Line Numerator Coefficients. Twenty coefficients for the polynomial in the Numerator of the rn equation.	unlimited	
LINE _ DEN _ COEFF (1-20)	Line Denominator Coefficients. Twenty coefficients for the polynomial in the Denominator of the rn equation.	unlimited	
SAMP _ NUM _ COEFF (1-20)	Sample Numerator Coefficients. Twenty coefficients for the polynomial in the Numerator of the cn equation.	unlimited	
SAMP _ DEN _ COEFF (1-20)	Sample Denominator Coefficients. Twenty coefficients for the polynomial in the Denominator of the cn equation.	unlimited	

Table 5. RPC metadata parameters in ICEYE Products

6. FURTHER INFORMATION

▶ FURTHER INFORMATION

The information provided in this document is intended to provide a comprehensive understanding of the Level 1 SAR Data Products provided by ICEYE. Further technical details can be found the attached references and from the ICEYE Product Document store. Feedback and question are welcome by contacting the ICEYE Customer Success Team via email at customer@iceye.com

7. REFERENCES

1	ESA, "The Sentinel Application Platform - SNAP," June 2020. [Online]. Available: http://step.esa.int/main/toolboxes/snap/.
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APPENDIX A SLC HDF5 METADATA COMPOSITION

This appendix describes all the metadata parameters that are included in the SLC HDF5 SAR Product.

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
acquisition_end_utc	ASCII	UTC time	UTC time for when the last pulse of the scene was sent	2019-03-10T18:20:00.307546
acquisition_mode	ASCII	text	Acquisition mode used	Stripmap, Spotlight
acquisition_prf	float64	Hz	Pulse Repetition Frequency used for the acquisition	4823.00343
acquisition_start_utc	ASCII	UTC time	UTC time for when the first pulse of the scene was sent	2019-03-10T18:19:50.316054
angX	vector of float64		X-component of the antenna pointing orientation	To be provided in future versions
angY	vector of float64		Y-component of the antenna pointing orientation	To be provided in future versions
angZ	vector of float64		Z-component of the antenna pointing orientation	To be provided in future versions
ant_elev_corr_flag	int64	flag	Flag indicating if antenna elevation pattern compensation was applied	1
antenna_pattern_compensation	vector of float64	numbers	Amplification factor applied for antenna pattern compensation (for each range sample)	[1.8106, 1.8103 ... 1.0956, 1.0957]
avg_scene_height	float64	meters	Average elevation over ellipsoid (calculated using SRTM or other low resolution global DEM)	661
azimuth_ground_spacing	float64	meters	Azimuth sample spacing in meters with the average ground projected velocity	1.44733

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
azimuth_looks	int64	number	Looks in azimuth direction (for SLC products it is 1)	1
azimuth_time_interval	float64	seconds	Time interval between azimuth samples in the SLC product. (=1/processing_prf)	2.07E-04
calibration_factor	float64	Number	Factor to be applied to calibrate detected products to absolute brightness intensity	0.000012341123
carrier_frequency	float64	Hz	Carrier frequency of the radar system, static parameter	9650000000
chirp_bandwidth	float64	Hz	Bandwidth used for radar pulse (defines achievable radar range resolution)	134000000
chirp_duration	float64	seconds	Duration of chirp	0.000041473
coord_center	[int32, int32, float64, float64]	coordinates	Centre coordinate [x(col), y(row),lat,lon]	[8440,22139, 34.86704, -117.99988]
coord_first_far	[int32, int32, float64, float64]	coordinates	First azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878, 1, 35.17738, -118,11233]
coord_first_near	[int32, int32, float64, float64]	coordinates	First azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1, 1, 35.12016, -117.74549]

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
coord_last_far	[int32, int32, float64, float64]	coordinates	Last azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878, 44298, 34.61222, -118.24414]
coord_last_near	[int32, int32, float64, float64]	coordinates	Last azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1, 44298, 34.55509, -117.88013]
dc_estimate_coeffs	2D array of float64, size MxN	Number	Doppler centroid coefficient as a 2D array, size MxN, where M is the number of DC estimates, and N is the DC polynomial order	[[5.417583e+03, 1.130813e+07, -8.125472e+09, 7.947223e+12], ... [5.417583e+03, 1.130813e+07, -8.125472e+09, 7.947223e+12]]
dc_estimate_poly_order	int64	Number	Order of polynomial describing one doppler centroid estimate	3
dc_estimate_time_utc	ASCII list	Time (UTC)	Timestamp for each doppler centroid estimate	['2019-03-10T18:19:51.775477'], ['2019-03-10T18:19:52.775477'], ['2019-03-10T18:19:53.775477'], ['2019-03-10T18:19:54.775477']
doppler_rate_coeffs	vector of float64	Number	Coefficients of doppler rate polynomial as a function of range time. Stored as a vector with size corresponding to the order of the doppler rate polynomial	[5.124592968269841e+03; -1.153864338674892e+06; 2.582540352459471e+08; -5.572042961000484e+10]

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
doppler_rate_poly_order	int64	Number	Order of polynomial describing doppler rate range dependence	3
first_pixel_time	float64	seconds	Two-way slant range time origin, corresponding to the near range (1st range sample)	0.004398670017
fsl_compensation	vector of float64	numbers	Amplification factor applied for free space loss compensation (for each range sample)	[1.0457, 1.0457 ... 1.0841, 1.0841]
geo_ref_system	ASCII	text	Geographic reference frame indicator for scene coordinates and orbit state vectors	WGS84
local_incidence_angle	vector of float64	Number	coefficients of the polynomial for calculating the incidence angle dependence in range	[2.67986035e+01; 8.66207416e-05; -5.61940883e-11; -1.73946139e-17; 8.22003978e-23]
incidence_center	float64	degrees	incidence angle in ground at middle range	23.5
look_side	ASCII	text	Look side of the acquisition, only 2 options LEFT or RIGHT	LEFT
heading	float64	degrees	Satellite heading at centre of imaging operation	191.08
mean_earth_radius	float64	meters	mean WGS84 ellipsoid radius over scene	6371346.049
mean_orbit_altitude	float64	meters	mean sensor altitude above WGS84 ellipsoid	595177.494

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
number_of_azimuth_samples	uint64	number	Number of azimuth samples (number of rows in binary data)	44298
number_of_dc_estimates	int64	Number	Number of doppler centroid estimates	9
number_of_range_samples	uint64	number	Number of range samples (number of columns in binary data)	16878
number_of_state_vectors	int64	number	Total number of orbit state vectors provided for the scene	120
orbit_absolute_number	int64	number	Absolute number of orbits since launch	1447
orbit_direction	ASCII	text	Specifies whether the orbit is in ascending or descending node at the time of acquisition	ASCENDING or DESCENDING
orbit_relative_number	int64	number	Relative number of orbit within the repeat cycle	1447
orbit_repeat_cycle	int64	number	Ground track repeat cycle (to be included)	99999

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
orbit_processing_level	ASCII	text	One of : ▶ PREDICTED (based on orbit propagation model) ▶ RAPID (uses onboard GPS data) ▶ PRECISE (corrections applied after GPS data received in ground using high precision orbit propagator) ▶ SCIENTIFIC (Uses precise ground-based measurements together with all above to post-fix orbit to best possible)	PRECISE
polarization	ASCII	text	Transmit and receive polarizations used	VV
posX	vector of float64	meters	X-component of state vector position, for each state vector	[-2401162517 ... -2456350660]
posY	vector of float64	meters	Y-component of state vector position, for each state vector	[-5201254993 ... -5253761907]
posZ	vector of float64	meters	Z-component of state vector position, for each state vector	[3963994744 ... 3859728760]
processing_prf	float64	Hz	Pulse Repetition Frequency used for the processing, defines azimuth sample spacing in time (can be higher than acquisition in cases where the Doppler frequency needs to be unfolded due to high variation of Doppler centroid with range)	9646.006859
processing_time	ASCII	UTC Time	Timestamp provided by the SAR processor saying when the image for processed	2020-05-27T05:01:49

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
processor_version	float64	number	Version number of the processor used to generate the product	(internal version numbering)
product_level	ASCII	text	Processing level	SLC, GRD
product_file	ASCII	text	File name of this product	ICEYE_X2_SLC_SM_16519_20200102T155349.h5
product_name	ASCII	Text	ICEYE_datasetID_eventID_(YYYYMMDD)T(HHMMSS)	ICEYE_2457_123123_20191201T056721
product_type	ASCII	text	Product type (if we have product names for different imaging modes)	Stripmap, StripmapHigh, Spotlight, SpotlightHigh
range_looks	int64	number	Looks in range direction (for SLC products it is 1)	3
range_sampling_rate	float64	Hz	Sampling rate used for digital sampling, defines range sample spacing in time	157500000
range_spread_comp_flag	int64	flag	Flag indicating if free space loss compensation was applied	1
RPC	See RPC metadata description in section 5.4			
s_i	as 'sample_precision'	number array	Real part of the SLC complex array	
s_q	as 'sample_precision'	number array	Imaginary part of the SLC complex array	
sample_precision	ASCII	text	Precision used for binary data samples	float32, uint16

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
satellite_look_angle	float64	degrees	Satellite look angle	23.5
satellite_name	ASCII	text	Name of the satellite	ICEYE-X2, ICEYE-X4...
slant_range_spacing	float64	meters	Spacing between two consecutive slant range samples in meters	0.9517220889
slant_range_to_first_pixel	float64	metres	Two-way slant range distance corresponding to near range (1st sample)	614576.9
spec_version	ASCII	Text	Version of the Level 1 Product Format Specification document	3
state_vector_time_utc	list of ASCII	UTC time	Timestamp for each orbit state vector	[2019-03-10T18:19:48.000000, ...]
total_processed_bandwidth_azimuth	float64	Hz	Doppler bandwidth used for azimuth compression (defines achievable azimuth resolution)	2893
tropo_range_delay	float64	meters	Mean signal path length correction (one way) that has been applied to correct for tropospheric propagation	2.4
velX		meters	X-component of state vector velocity, for each state vector	[-3285.698 ... -3245.220]
velY	vector of float64	meters	Y-component of state vector velocity, for each state vector	[-3162.667 ... -3051.016]
velZ	vector of float64	meters	Z-component of state vector velocity, for each state vector	[-6130.372 ... -6208.463]

HDF5 TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
window_ function_ azimuth	ASCII	text	Windowing function used over azimuth frequencies	taylor_20_4
window_ function_ range	ASCII	text	Windowing function used over range frequencies	taylor_20_4
zerodoppler_ end_utc	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the last scene pulse	2019-03-10T18:20:00.960210
zerodoppler_ start_utc	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the first scene pulse	2019-03-10T18:19:51.775477

Table 6. SLC HDF5 metadata description

APPENDIX B SLC AUXILIARY XML METADATA COMPOSITION

This appendix describes all the metadata parameters that are included in the auxiliary XML file associated with the SLC HDF5 SAR Product. There are several sub-blocks within the XML metadata block that are described in the following subsections.

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ACQUISITION_END_UTC	ASCII	UTC time	UTC time for when the last pulse of the scene was sent	2019-03-10T18:20:00.307546
ACQUISITION_MODE	ASCII	text	Acquisition mode used	Stripmap, Spotlight
ACQUISITION_PRF	float64	Hz	Pulse Repetition Frequency used for the acquisition	4823.00343
ACQUISITION_START_UTC	ASCII	UTC time	UTC time for when the first pulse of the scene was sent	2019-03-10T18:19:50.316054
ORBIT_STATE_VECTORS	See Orbit State Vector XML Block description in Table 8			
ANT_ELEV_CORR_FLAG	int64	flag	Flag indicating if antenna elevation pattern compensation was applied	1
AVG_SCENE_HEIGHT	float64	meters	Average elevation over ellipsoid (calculated using SRTM or other low resolution global DEM)	661
AZIMUTH_GROUND_SPACING	float64	meters	Azimuth sample spacing in meters with the average ground projected velocity	1.44733
AZIMUTH_LOOKS	int64	number	Looks in azimuth direction (for SLC it is 1)	1
AZIMUTH_TIME_INTERVAL	float64	seconds	Time interval between azimuth samples in the SLC product. (=1/processing_prf)	2.07E-04

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
CALIBRATION_FACTOR	float64	number	Factor to be applied to calibrate detected products to absolute brightness intensity	0.000012341123
CARRIER_FREQUENCY	float64	Hz	Carrier frequency of the radar system, static parameter	9650000000
CHIRP_BANDWIDTH	float64	Hz	Bandwidth used for radar pulse (defines achievable radar range resolution)	134000000
CHIRP_DURATION	float64	seconds	Duration of chirp	0.000041473
COORD_CENTER	[int32, int32, float64, float64]	coordinates	Centre coordinate [x(col), y(row),lat,lon]	[8440,22139,34.86704,-117.99988]
COORD_FIRST_FAR	[int32, int32, float64, float64]	coordinates	First azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878,1,35.17738,-118,11233]
COORD_FIRST_NEAR	[int32, int32, float64, float64]	coordinates	First azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,1,35.12016,-117.74549]
COORD_LAST_FAR	[int32, int32, float64, float64]	coordinates	Last azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878,44298,34.61222,-118.24414]

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
COORD_LAST_NEAR	[int32, int32, float64, float64]	coordinates	Last azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,44298,34.55509,-117.88013]
DOPPLER_CENTROID_COEFFICIENTS	see Doppler Centroid XML Metadata Block description in Table 9			
DOPPLER_RATE	see Doppler Rate Coefficients XML Metadata Block description in Table 10			
FIRST_PIXEL_TIME	float64	seconds	Two-way slant range time origin, corresponding to the near range (1st range sample)	0.004398670017
GEO_REF_SYSTEM	ASCII	text	Geographic reference frame indicator for scene coordinates and orbit state vectors	WGS84
HEADING	float64	degrees	Satellite heading at centre of imaging operation	191.08
INCIDENCE_CENTER	float64	degrees	incidence angle in ground at middle range	18.9
INCIDENCE_FAR	float64	degrees	incidence angle in ground at far range	21.0
INCIDENCE_NEAR	float64	degrees	incidence angle in ground at near range	16.6
LOOK_SIDE	ASCII	text	Look side of the acquisition, only 2 options LEFT or RIGHT	LEFT
MEAN_EARTH_RADIUS	float64	meters	mean WGS84 ellipsoid radius over scene	6371346.049

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
MEAN_ORBIT_ALTITUDE	float64	meters	mean sensor altitude above WGS84 ellipsoid	595177.494
NUMBER_OF_AZIMUTH_SAMPLES	uint64	number	Number of azimuth samples (number of rows in binary data)	44298
NUMBER_OF_DC_ESTIMATIONS	int64	number	Number of doppler centroid estimates	9
NUMBER_OF_RANGE_SAMPLES	uint64	number	Number of range samples (number of columns in binary data)	16878
N/A	int64	number	Total number of orbit state vectors provided for the scene	120
ORBIT_ABSOLUTE_NUMBER	int64	number	Absolute number of orbits since launch	1447
ORBIT_DIRECTION	ASCII	text	Specifies whether the orbit is in ascending or descending node at the time of acquisition	ASCENDING or DESCENDING
ORBIT_RELATIVE_NUMBER	int64	number	Relative number of orbit within the repeat cycle	1447
ORBIT_REPEAT_CYCLE	int64	number	Ground track repeat cycle (to be included)	99999
ORBIT_STATE_VECTORS	See Orbit State Vector XML Block description in table Table 8			

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ORBIT_PROCESSING_LEVEL	ASCII	Text	One of : ▶ PREDICTED (based on orbit propagation model) ▶ RAPID (uses onboard GPS data) ▶ PRECISE (corrections applied after GPS data received in ground using high precision orbit propagator) ▶ SCIENTIFIC (Uses precise ground-based measurements together with all above to post-fix orbit to best possible)	PRECISE
POLARIZATION	ASCII	text	Transmit and receive polarizations used	VV
PROCESSING_PRF	float64	Hz	Pulse Repetition Frequency used for the processing, defines azimuth sample spacing in time (can be higher than acquisition in cases where the Doppler frequency needs to be unfolded due to high variation of Doppler centroid with range)	9646.006859
PROCESSING_TIME	ASCII	UTC Time	Timestamp provided by the SAR processor saying when the image for processed	2020-05-27T05:01:49
PROCESSOR_VERSION	float64	number	Version number of the processor used to generate the product	(internal version numbering)
PRODUCT_LEVEL	ASCII	text	Processing level	SLC, GRD

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
PRODUCT_FILE	ASCII	text	File name of this product	ICEYE_X2_ SLC_SM_16519_ 20200102T155349.h5
PRODUCT_NAME	ASCII	Text	ICEYE_datasetID_eventID_ (YYYYMMDD)T(HHMMSS)	ICEYE_2457_123123_201 91201T056721
PRODUCT_TYPE	ASCII	text	Product type (if we have product names for different imaging modes)	Stripmap, StripmapHigh, Spotlight, SpotlightHigh
RANGE_LOOKS	int64	number	Looks in range direction (for SLC products it is 1)	3
RANGE_ SAMPLING_ RATE	float64	Hz	Sampling rate used for digital sampling, defines range sample spacing in time	157500000
RANGE_ SPREAD_COMP_ FLAG	int64	flag	Flag indicating if free space loss compensation was applied	1
RPC	See RPC metadata description in section 5.4			
SAMPLE_ PRECISION	ASCII	text	Precision used for binary data samples	float32, uint16
SATELLITE_ LOOK_ANGLE	float64	degrees	Satellite look angle	23.5
SATELLITE_ NAME	ASCII	text	Name of the satellite	ICEYE-X2, ICEYE-X4...
SLANT_RANGE_ SPACING	float64	meters	Spacing between two consecutive slant range samples in meters	0.9517220889
SPEC_VERSION	ASCII	Text	Version of the Level 1 Product Format Specification document	3

SLC-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
TOTAL_PROCESSED_BANDWIDTH_AZIMUTH	float64	Hz	Doppler bandwidth used for azimuth compression (defines achievable azimuth resolution)	2893
TROPO_RANGE_DELAY	float64	meters	Mean signal path length correction (one way) that has been applied to correct for tropospheric propagation	2.4
WINDOW_FUNCTION_AZIMUTH	ASCII	text	Windowing function used over azimuth frequencies	taylor_20_4
WINDOW_FUNCTION_RANGE	ASCII	text	Windowing function used over range frequencies	taylor_20_4
ZERODOPPLER_END_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the last scene pulse	2019-03-10T18:20:00.960210
ZERODOPPLER_START_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the first scene pulse	2019-03-10T18:19:51.775477

Table 7. SLC XML Metadata description

B.1 ORBIT STATE VECTOR METADATA XML BLOCK

TAG	DESCRIPTION
<Orbit _ State _ Vectors>	On block per XML file
<count>n</count>	Integer number specifying the number of orbit state vectors stored in this XML Orbit_state_vectors block. There then follows n <orbit_vector>s
<orbit _ vector>	Block defining one State vector. Each state vector contains the following
<number>N</number>	Index of this state vector
<time>t</time>	UTC time of this state vector
<posX>x-position</posX> <posY>y-position</posY> <posZ>z-position</posZ>	Earth-Centred, Earth-Fixed position of satellite (X,Y,Z) at time t
<velX>x-velocity</velX> <velY>y-velocity</velY> <velZ>z-velocity</velZ>	Earth-Centred, Earth-Fixed velocity of satellite (X,Y,Z) at time t
</orbit _ vector>	
...	Orbit_vector block repeats n times
</Orbit _ State _ Vectors>	

Table 8. Orbit State Vector XML metadata block description

B.2 DOPPLER CENTROID XML METADATA BLOCK

TAG	DESCRIPTION
<number _ of _ dc _ estimations>N</number _ of _ dc _ estimations>	Number of Doppler centroid polynomials in the Product
<dc _ estimate _ poly _ order>O</dc _ estimate _ poly _ order>	Order of each Doppler centroid polynomial
<Doppler _ Centroid _ Coefficients>	Start of Doppler centroid coefficient block
<dc _ coefficients _ list>	Start of coefficients block for this DC polynomial
<number>n</number>	Index of this DC polynomial
<zero _ doppler _ time>time</zero _ doppler _ time>	Time corresponding to zero Doppler for this polynomial
<reference _ pixel _ time>tref</reference _ pixel _ time>	Time corresponding to tref for this polynomial
<coefficient>	XML block for coefficient C out of O-1 coefficients for this polynomial
<number>C</number>	Index of coefficient
<value>v</value>	Value of coefficient as floating point number
</coefficient>	End of coefficient block
...	Coefficient blocks repeats O times
</dc _ coefficients _ list>	End of DC coefficients block for this polynomial
...	Doppler centroid coefficients block repeats N times
</Doppler _ Centroid _ Coefficients>	End of Doppler centroid coefficients XML block

Table 9. Doppler Centroid XML metadata block description

B.3 DOPPLER RATE COEFFICIENTS XML METADATA BLOCK

TAG	DESCRIPTION
<doppler _ rate _ poly _ order>O</doppler _ rate _ poly _ order>	Order of polynomial describing doppler rate range dependence
<Doppler _ Rate>	Start of Doppler rate XML block
<reference _ pixel _ time>t</reference _ pixel _ time>	Time corresponding to tref for this polynomial
<coefficient>	Start of coefficient XML block
<number>n</number>	Coefficient order
<value>v</value>	Coefficient value
</coefficient>	End of coefficient XML block
...	Coefficient XML block repeats O-1 times
</Doppler _ Rate>	End of Doppler_rate XML block

Table 10. Doppler rate XML metadata block description

APPENDIX C GRD GEOTIFF METADATA COMPOSITION

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ACQUISITION_END_UTC	ASCII	UTC time	UTC time for when the last pulse of the scene was sent	2019-03-10T18:20:00.307546
ACQUISITION_MODE	ASCII	text	Acquisition mode used	Stripmap, Spotlight
ACQUISITION_PRF	float64	Hz	Pulse Repetition Frequency used for the acquisition	4823.00343
ACQUISITION_START_UTC	ASCII	UTC time	UTC time for when the first pulse of the scene was sent	2019-03-10T18:19:50.316054
ANT_ELEV_CORR_FLAG	int64	flag	Flag indicating if antenna elevation pattern compensation was applied	1
AVG_SCENE_HEIGHT	float64	meters	Average elevation over ellipsoid (calculated using SRTM or other low resolution global DEM)	661
AZIMUTH_SPACING	float64	meters	Azimuth sample spacing in meters with the average ground projected velocity	1.44733
AZIMUTH_LOOK_BANDWIDTH	float64	Hz	Bandwidth of each look in range (only for GRD products)	1157.2
AZIMUTH_LOOK_OVERLAP	float64	Hz	Overlap of adjacent looks in azimuth (only for GRD products)	289.3
AZIMUTH_LOOKS	int64	number	Looks in azimuth direction (for SLC products it is 1)	3

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
AZIMUTH_TIME_INTERVAL	float64	seconds	Time interval between azimuth samples in the SLC product. (=1/processing_prf)	2.07E-04
CALIBRATION_FACTOR	float64	number	Factor to be applied to calibrate detected products to absolute brightness intensity	0.000012341123
CARRIER_FREQUENCY	float64	Hz	Carrier frequency of the radar system, static parameter	9650000000
CHIRP_BANDWIDTH	float64	Hz	Bandwidth used for radar pulse (defines achievable radar range resolution)	134000000
CHIRP_DURATION	float64	seconds	Duration of chirp	0.000041473
COORD_CENTER	[int32, int32, float64, float64]	coords	Centre coordinate [x(col), y(row),lat,lon]	[8440,22139,34.86704,-117.99988]
COORD_FIRST_FAR	[int32, int32, float64, float64]	coords	First azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878,1,35.17738,-118,11233]
COORD_FIRST_NEAR	[int32, int32, float64, float64]	coords	First azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,1,35.12016,-117.74549]
COORD_LAST_FAR	[int32, int32, float64, float64]	coords	Last azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878,44298,34.61222,-118.24414]

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
COORD_LAST_ NEAR	[int32, int32, float64, float64]	coords	Last azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,44298,34.55509,-117.88013]
DC_ESTIMATE_ COEFFS	2D array of float64, size MxN	number	Doppler centroid coefficient as a 2D array, size MxN, where M is the number of DC estimates, and N is the DC polynomial order	[[5.417583e+03, 1.130813e+07, -8.125472e+09, 7.947223e+12], ... [5.417583e+03, 1.130813e+07, -8.125472e+09, 7.947223e+12]]
DC_ESTIMATE_ POLY_ORDER	int64	number	Order of polynomial describing one doppler centroid estimate	3
DC_ESTIMATE_ TIME_UTC	ASCII list	Time (UTC)	Timestamp for each doppler centroid estimate	['2019-03-10T18:19:51.775477'], ['2019-03-10T18:19:52.775477'], ['2019-03-10T18:19:53.775477'], ['2019-03-10T18:19:54.775477']
DOPPLER_RATE_ COEFFS	vector of float64	number	Coefficients of doppler rate polynomial as a function of range time. Stored as a vector with size corresponding to the order of the doppler rate polynomial	[5.124592968269841e+03; -1.153864338674892e+06; 2.582540352459471e+08; -5.572042961000484e+10]

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
DOPPLER_RATE_POLY_ORDER	int64	number	Order of polynomial describing doppler rate range dependence	3
GCP_TERRAIN_MODEL	ASCII	text	Options are WGS84 for Ellipsoid, EGM96 for GEOID, DEM for DEM based	DEM
GEO_REF_SYSTEM	ASCII	text	Geographic reference frame indicator for scene coordinates and orbit state vectors	WGS84
GRD_AMPLITUDE	as 'sample_precision'	number array	Amplitude array (only for GRD products). Sigma-nought conversion factor of sin(inc_angle) applied.	
GRSR_COEFFICIENTS	vector of float64	number	ground range to slant range polynomial coefficients (only for GRD product)	[6.467483312430216e+05; 0.47388031307797884; 6.685331046296479e-07; -4.928145432555108e-13; 5.0525558404285224e-20]
GRSR_GROUND_RANGE_ORIGIN		number	ground range origin for GRSR conversion	0
GRSR_POLY_ORDER	int64	number	Order of polynomial describing ground range to slant range projection dependence (only for GRD product)	4
GRSR_ZERO_DOPPLER_TIME	ASCII	UTC time	ground range origin zero Doppler time	2019-04-08T14:50:13.120113

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
HEADING	float64	degrees	Satellite heading at centre of imaging operation	191.08
INCIDENCE_ANGLE_COEFFICIENTS	vector of float64	number	coefficients of the polynomial for calculating the incidence angle dependence in range	[2.67986035e+01; 8.66207416e-05; -5.61940883e-11; -1.73946139e-17; 8.22003978e-23]
INCIDENCE_ANGLE_GROUND_RANGE_ORIGIN	float64	number	incidence angle origin in ground range, for calculating incidence angle dependence in range	0
INCIDENCE_ANGLE_POLY_ORDER	int64	number	order of the polynomial for calculating the incidence angle dependence in range	4
INCIDENCE_ANGLE_ZERO_DOPPLER_TIME	ASCII	UTC time	incidence angle origin zero Doppler time	2019-04-08T14:50:13.120113
INCIDENCE_CENTER	float64	degrees	incidence angle in ground at middle range	18.9
INCIDENCE_FAR	float64	degrees	incidence angle in ground at far range	21.0
INCIDENCE_NEAR	float64	degrees	incidence angle in ground at near range	16.6
LOOK_SIDE	ASCII	text	Look side of the acquisition, only 2 options LEFT or RIGHT	LEFT
MEAN_EARTH_RADIUS	float64	meters	mean WGS84 ellipsoid radius over scene	6371346.049

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
MEAN_ORBIT_ALTITUDE	float64	meters	mean sensor altitude above WGS84 ellipsoid	595177.494
NUMBER_OF_AZIMUTH_SAMPLES	uint64	number	Number of azimuth samples (number of rows in binary data)	44298
NUMBER_OF_DC_ESTIMATIONS	int64	number	Number of doppler centroid estimates	9
NUMBER_OF_RANGE_SAMPLES	uint64	number	Number of range samples (number of columns in binary data)	16878
NUMBER_OF_STATE_VECTORS	int64	number	Total number of orbit state vectors provided for the scene	120
ORBIT_ABSOLUTE_NUMBER	int64	number	Absolute number of orbits since launch	1447
ORBIT_DIRECTION	ASCII	text	Specifies whether the orbit is in ascending or descending node at the time of acquisition	ASCENDING or DESCENDING
ORBIT_RELATIVE_NUMBER	int64	number	Relative number of orbit within the repeat cycle	1447
ORBIT_REPEAT_CYCLE	int64	number	Ground track repeat cycle (to be included)	99999

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ORBIT_PROCESSING_LEVEL	ASCII	Text	One of : ▶ PREDICTED (based on orbit propagation model) ▶ RAPID (uses onboard GPS data) ▶ PRECISE (corrections applied after GPS data received in ground using high precision orbit propagator) ▶ SCIENTIFIC (Uses precise ground-based measurements together with all above to post-fix orbit to best possible)	PRECISE
POLARIZATION	ASCII	text	Transmit and receive polarizations used	VV
POSX	vector of float64	meters	X-component of state vector position, for each state vector	[-2401162517... -2456350660]
POSY	vector of float64	meters	Y-component of state vector position, for each state vector	[-5201254993... -5253761907]
POSZ	vector of float64	meters	Z-component of state vector position, for each state vector	[3963994744... 3859728760]

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
PROCESSING_PRF	float64	Hz	Pulse Repetition Frequency used for the processing, defines azimuth sample spacing in time (can be higher than acquisition in cases where the Doppler frequency needs to be unfolded due to high variation of Doppler centroid with range)	9646.006859
PROCESSING_TIME	ASCII	UTC Time	Timestamp provided by the SAR processor saying when the image for processed	2020-05-27T05:01:49
PROCESSOR_VERSION	float64	number	Version number of the processor used to generate the product	(internal version numbering)
PRODUCT_LEVEL	ASCII	text	Processing level	SLC, GRD
PRODUCT_FILE	ASCII	text	File name of this product	ICEYE_X2_SLC_SM_16519_20200102T155349.h5
PRODUCT_NAME	ASCII	Text	ICEYE_datasetID_eventID_(YYYYMMDD)T(HHMMSS)	ICEYE_2457_123123_20191201T056721
PRODUCT_TYPE	ASCII	text	Product type (if we have product names for different imaging modes)	Stripmap, StripmapHigh, Spotlight, SpotlightHigh

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
RANGE_LOOK_BANDWIDTH	float64	Hz	Bandwidth of each look in range (only for GRD products)	53600000
RANGE_LOOK_OVERLAP	float64	Hz	Overlap of adjacent looks in range (only for GRD products)	13400000
RANGE_LOOKS	int64	number	Looks in range direction (for SLC products it is 1)	3
RANGE_SAMPLING_RATE	float64	Hz	Sampling rate used for digital sampling, defines range sample spacing in time	157500000
RANGE_SPREAD_COMP_FLAG	int64	flag	Flag indicating if free space loss compensation was applied	1
RPC	See RPC metadata description in section 5.4			
SAMPLE_PRECISION	ASCII	text	Precision used for binary data samples	float32, uint16
SATELLITE_LOOK_ANGLE	float64	degrees	Satellite look angle	23.5
SATELLITE_NAME	ASCII	text	Name of the satellite	ICEYE-X2, ICEYE-X4...
RANGE_SPACING	float64	meters	Spacing between two consecutive slant range samples in meters	0.9517220889
SLANT_RANGE_TO_FIRST_PIXEL	float64	metres	Two-way slant range distance corresponding to near range (1st sample)	614576.9589124141

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
SPEC_VERSION	ASCII	Text	Version of the Level 1 Product Format Specification document	3
STATE_VECTOR_ TIME_UTC	list of ASCII	UTC time	Timestamp for each orbit state vector	[2019-03-10T18:19:48.000000, ...]
TOTAL_ PROCESSED_ BANDWIDTH_ AZIMUTH	float64	Hz	Doppler bandwidth used for azimuth compression (defines achievable azimuth resolution)	2893
TROPO_RANGE_ DELAY	float64	meters	Mean signal path length correction (one way) that has been applied to correct for tropospheric propagation	2.4
VELX	vector of float64	meters	X-component of state vector velocity, for each state vector	[-3285.698...-3245.220]
VELY	vector of float64	meters	Y-component of state vector velocity, for each state vector	[-3162.667...-3051.016]
VELZ	vector of float64	meters	Z-component of state vector velocity, for each state vector	[-6130.372...-6208.463]
WINDOW_ FUNCTION_ AZIMUTH	ASCII	text	Windowing function used over azimuth frequencies	taylor_20_4
WINDOW_ FUNCTION_RANGE	ASCII	text	Windowing function used over range frequencies	taylor_20_4

GEOTIFF TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ZERODOPPLER_END_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the last scene pulse	2019-03-10T18:20:00.960210
ZERODOPPLER_START_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the first scene pulse	2019-03-10T18:19:51.775477

Table 11. GRD GeoTIFF Metadata description

APPENDIX D GRD AUXILIARY XML METADATA COMPOSITION

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ACQUISITION_END_UTC	ASCII	UTC time	UTC time for when the last pulse of the scene was sent	2019-03-10T18:20:00.307546
ACQUISITION_MODE	ASCII	text	Acquisition mode used	Stripmap, Spotlight
ACQUISITION_PRF	float64	Hz	Pulse Repetition Frequency used for the acquisition	4823.00343
ACQUISITION_START_UTC	ASCII	UTC time	UTC time for when the first pulse of the scene was sent	2019-03-10T18:19:50.316054
ANT_ELEV_CORR_FLAG	int64	flag	Flag indicating if antenna elevation pattern compensation was applied	1
AVG_SCENE_HEIGHT	float64	meters	Average elevation over ellipsoid (calculated using SRTM or other low resolution global DEM)	661
AZIMUTH_SPACING	float64	meters	Azimuth sample spacing in meters with the average ground projected velocity	1.44733
AZIMUTH_LOOK_BANDWIDTH	float64	Hz	Bandwidth of each look in range (only for GRD products)	1157.2
AZIMUTH_LOOK_OVERLAP	float64	Hz	Overlap of adjacent looks in azimuth (only for GRD products)	289.3
AZIMUTH_LOOKS	int64	number	Looks in azimuth direction (for SLC products it is 1)	3
AZIMUTH_TIME_INTERVAL	float64	seconds	Time interval between azimuth samples in the SLC product. (=1/processing_prf)	2.07E-04

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
CALIBRATION_FACTOR	float64	number	Factor to be applied to calibrate detected products to absolute brightness intensity	0.000012341123
CARRIER_FREQUENCY	float64	Hz	Carrier frequency of the radar system, static parameter	9650000000
CHIRP_BANDWIDTH	float64	Hz	Bandwidth used for radar pulse (defines achievable radar range resolution)	134000000
CHIRP_DURATION	float64	seconds	Duration of chirp	0.000041473
COORD_CENTER	[int32, int32, float64, float64]	coord	Centre coordinate [x(col), y(row),lat,lon]	[8440,22139,34.86704,-117.99988]
COORD_FIRST_FAR	[int32, int32, float64, float64]	coord	First azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878,1,35.17738,-118,11233]
COORD_FIRST_NEAR	[int32, int32, float64, float64]	coord	First azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,1,35.12016,-117.74549]
COORD_LAST_FAR	[int32, int32, float64, float64]	coord	Last azimuth row far range coordinate. [x(col), y(row),lat,lon]	[16878, 44298,34.61222, -118.24414]
COORD_LAST_NEAR	[int32, int32, float64, float64]	coord	Last azimuth row near range coordinate. [x(col), y(row),lat,lon]	[1,44298,34.55509,-117.88013]
DOPPLER_CENTROID_COEFFICIENTS	see Doppler Centroid XML Metadata Block description in Table 9			
DOPPLER_RATE	see Doppler Rate Coefficients XML Metadata Block description in Table 10			

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
FIRST_PIXEL_TIME	float64	seconds	Two-way slant range time origin, corresponding to the near range (1st range sample)	0.004398670017
GCP_TERRAIN_MODEL	ASCII	text	Options are WGS84 for Ellipsoid, EGM96 for GEOID, DEM for DEM based	
GEO_REF_SYSTEM	ASCII	text	Geographic reference frame indicator for scene coordinates and orbit state vectors	WGS84
GRSR_COEFFICIENTS	See Ground Range to Slant Range XML metadata block description in Table 13			
HEADING	float64	degrees	Satellite heading at centre of imaging operation	
INCIDENCE_ANGLE_COEFFICIENTS	See Incidence Angle XML metadata block description in Table 14			
INCIDENCE_ANGLE_POLY_ORDER	int64	number	order of the polynomial for calculating the incidence angle dependence in range	4
INCIDENCE_CENTER	float64	degrees	incidence angle in ground at middle range	18.9
INCIDENCE_FAR	float64	degrees	incidence angle in ground at far range	21.0
INCIDENCE_NEAR	float64	degrees	incidence angle in ground at near range	16.6
LOOK_SIDE	ASCII	text	Look side of the acquisition, only 2 options LEFT or RIGHT	LEFT

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
MEAN_EARTH_RADIUS	float64	meters	mean WGS84 ellipsoid radius over scene	6371346.049
MEAN_ORBIT_ALTITUDE	float64	meters	mean sensor altitude above WGS84 ellipsoid	595177.494
NUMBER_OF_AZIMUTH_SAMPLES	uint64	number	Number of azimuth samples (number of rows in binary data)	44298
NUMBER_OF_DC_ESTIMATIONS	int64	number	Number of doppler centroid estimates	9
NUMBER_OF_RANGE_SAMPLES	uint64	number	Number of range samples (number of columns in binary data)	16878
ORBIT_ABSOLUTE_NUMBER	int64	number	Absolute number of orbits since launch	1447
ORBIT_DIRECTION	ASCII	text	Specifies whether the orbit is in ascending or descending node at the time of acquisition	ASCENDING or DESCENDING
ORBIT_RELATIVE_NUMBER	int64	number	Relative number of orbit within the repeat cycle	1447
ORBIT_REPEAT_CYCLE	int64	number	Ground track repeat cycle (to be included)	99999
ORBIT_STATE_VECTORS	See Orbit State Vector XML Block description in Table 8			

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
ORBIT_PROCESSING_LEVEL	ASCII	Text	One of: ▶ PREDICTED (based on orbit propagation model) ▶ RAPID (uses onboard GPS data) ▶ PRECISE (corrections applied after GPS data received in ground using high precision orbit propagator ▶ SCIENTIFIC (Uses precise ground-based measurements together with all above to post-fix orbit to best possible)	
POLARIZATION	ASCII	text	Transmit and receive polarizations used	VV
PROCESSING_PRF	float64	Hz	Pulse Repetition Frequency used for the processing, defines azimuth sample spacing in time (can be higher than acquisition in cases where the Doppler frequency needs to be unfolded due to high variation of Doppler centroid with range)	9646.006859
PROCESSING_TIME	ASCII	UTC Time	Timestamp provided by the SAR processor saying when the image for processed	2020-05-27T05:01:49
PROCESSOR_VERSION	float64	number	Version number of the processor used to generate the product	(internal version numbering)
PRODUCT_LEVEL	ASCII	text	Processing level	SLC, GRD

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
PRODUCT_FILE	ASCII	text	File name of this product	ICEYE_X2_ SLC_SM_ 16519_ 20200102T155349.h5
PRODUCT_NAME	ASCII	Text	ICEYE_datasetID_eventID_ (YYYYMMDD)T(HHMMSS)	ICEYE_2457_123123_ 20191201T056721
PRODUCT_TYPE	ASCII	text	Product type (if we have product names for different imaging modes)	Stripmap, StripmapHigh, Spotlight, SpotlightHigh
RANGE_LOOK_ BANDWIDTH	float64	Hz	Bandwidth of each look in range (only for GRD products)	53600000
RANGE_LOOK_ OVERLAP	float64	Hz	Overlap of adjacent looks in range (only for GRD products)	13400000
RANGE_LOOKS	int64	number	Looks in range direction (for SLC products it is 1)	3
RANGE_ SAMPLING_RATE	float64	Hz	Sampling rate used for digital sampling, defines range sample spacing in time	157500000
RANGE_SPREAD_ COMP_FLAG	int64	flag	Flag indicating if free space loss compensation was applied	1
RPC	See RPC metadata description in section 5.4			
SAMPLE_ PRECISION	ASCII	text	Precision used for binary data samples	float32, uint16
SATELLITE_ LOOK_ANGLE	float64	degrees	Satellite look angle	23.5
SATELLITE_NAME	ASCII	text	Name of the satellite	ICEYE-X2, ICEYE-X4...

GEOTIFF-XML TAG	TYPE	UNIT	DESCRIPTION	EXAMPLE
RANGE_SPACING	float64	meters	Spacing between two consecutive slant range samples in meters	0.9517220889
SLANT_RANGE_TO_FIRST_PIXEL	float64	metres	Two-way slant range distance corresponding to near range (1st sample)	614576.9
SPEC_VERSION	ASCII	Text	Version of the Level 1 Product Format Specification document	3
TOTAL_PROCESSED_BANDWIDTH_AZIMUTH	float64	Hz	Doppler bandwidth used for azimuth compression (defines achievable azimuth resolution)	2893
TROPO_RANGE_DELAY	float64	meters	Mean signal path length correction (one way) that has been applied to correct for tropospheric propagation	2.4
WINDOW_FUNCTION_AZIMUTH	ASCII	text	Windowing function used over azimuth frequencies	taylor_20_4
WINDOW_FUNCTION_RANGE	ASCII	text	Windowing function used over range frequencies	taylor_20_4
ZERODOPPLER_END_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the last scene pulse	2019-03-10T18:20:00.960210
ZERODOPPLER_START_UTC	ASCII	UTC time	Time corresponding to when the satellite was at the zero Doppler position for the first scene pulse	2019-03-10T18:19:51.775477

Table 12. GRD XML metadata description

D.1 GROUND RANGE TO SLANT RANGE XML METADATA BLOCK

TAG	DESCRIPTION
< grsr _ poly _ order>O</grsr _ poly _ order>	Order of polynomial describing ground range to slant range projection dependence (only for GRD product)
< GRSR _ Coefficients>	Start of GRSR rate XML block
<coefficient>	Start of coefficient XML block
<number>n</number>	Coefficient order
<value>v</value>	Coefficient value
</coefficient>	End of coefficient XML block
...	Coefficient XML block repeats O-1 times
<zero _ doppler _ time>time</zero _ doppler _ time>	ground range origin zero Doppler time
<ground _ range _ origin>0.0</ground _ range _ origin>	ground range origin for GRSR conversion
</GRSR _ Coefficients>	End of GRSR XML block

Table 13. Ground range to slant range XML metadata block description

D.2 INCIDENCE ANGLE XML METADATA BLOCK

TAG	DESCRIPTION
<incidence _ angle _ poly _ order>O</ incidence _ angle _ poly _ order>	order of the polynomial for calculating the incidence angle dependence in range
<Incidence _ Angle _ Coefficients>	Start of GRSR rate XML block coefficients for the polynomial for calculating the incidence angle dependence in range
<coefficient>	Start of coefficient XML block
<number>n</number>	Coefficient order
<value>v</value>	Coefficient value
</coefficient>	End of coefficient XML block
...	Coefficient XML block repeats O-1 times
<zero _ doppler _ time>time</ zero _ doppler _ time>	Incidence angle origin zero Doppler time
<ground _ range _ origin>0.0</ ground _ range _ origin>	Incidence angle origin in ground range, for calculating incidence angle dependence in range
</Incidence _ Angle _ Coefficients>	End of GRSR XML block

Table 14. Incidence angle XML metadata block description

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