BIOMASS Product Performance Description

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1. Introduction

1.1. Context

BIOMASS is ESA's 7th Earth Explorer mission. The purpose of the BIOMASS is to reduce the uncertainty in the worldwide spatial distribution and dynamics of forest biomass in order to improve current assessments and future projections of the global carbon cycle. This objective will be achieved by the implementation of a P-band SAR mission, providing global maps of forest biomass stocks, forest disturbance and growth.
The BIOMASS mission will also provide 3D views of forests through the "tomographic" phase and will also support additional science needs arising from the opportunity to explore the Earth for the first time with a P-band SAR system from space offering the possibility to "see" below the vegetated areas and in beneath bare soil or icy regions.

To achieve its challenging objectives, the BIOMASS mission requires a specific data processing strategy that combines different technologies at different processing level in order to generate the final Above Ground Biomass global map.

1.2. Scope of the document

This document includes a description of the complete family of BIOMASS L1, L2, and L3 products, defining for each type of product its main system, processing and image quality characteristics.
This document is structured as follows:

- Section 2: BIOMASS Mission Overview;
- Section 3: Description of the BIOMASS product family tree;
- Section 4: Detailed definition of each product of the tree;
- Section 5: Glossary of the terminology used for products definition;
- Section 6: Plots of main parameters round-orbit variation.

1.3. Acronyms

Acronym	Description
ACM	Average Covariance Matrix
AD	Applicable Document
AGB	Above Ground Biomass
ARESYS	Advanced Remote Sensing and Systems
ATBD	Algorithm Theoretical Basis Document

Acronym	Description
BPS	BIOMASS Processing Suite
CFM	Computed Forest mask (by FD processor)
DEM	Digital Elevation Model
DGM	Detected Ground-range Multi-looked
ESA	European Space Agency
FA	Forest Assembly
FD	Forest Disturbance
FH	Forest Height
FNF	Forest/Non-Forest mask
GC	Global Cycle
GN	Ground cancelled calibrated backscatter
GPP	Ground Processor Prototype
INT	Interferometric Phase
L0	Level-0 product
L1a	Level-1a product
L1b	Level-1b product
L1c	Level-1c product
L2a	Level-2a product
L2b	Level-2b product
L3	Level-3 product
PARC	Polarimetric Active Radar Calibrator
PDGS	Payload Data Ground Segment
PFD	Product Format Specification Document
PRF	Pulse Repetition Frequency
PRI	Pulse Repetition Interval
RD	Reference Document
SAR	Synthetic Aperture Radar
SCS	Single-look Complex Slant-range
SRD	System Requirements Document
STA	Coregistered Stack
SWL	Sampling Window Length
SWP	Sampling Window Position
TBC	To Be Confirmed

Acronym	Description
TBD	To Be Defined
TOM	Tomographic Phase

1.4. Applicable documents

[AD1] BPS_L1_PFD, BIOMASS L1a,b,c products format specification, I/R 1/2/5
[AD2] BIO-UDB-ADSF-SY-1000695798, BIOMASS Instrument RDB, I/R 23/0
[AD3] EOCFI-FTD-046, Example Orbit Files for BIOMASS INT and TOM Phases – File Transfer Document, I/R 1/3
[AD4] BIO-TCN-ASU-SY-00012, Biomass - Coordinate System Definition Document, I/R 6/0
[AD5] BIOMASS L1 SAR ATBD, BIO-BPS-L1-SAR-ATBD-ARE-010165, I/R, 1/1/2
[AD6] BIOMASS L1c STACK ATBD, BIO-BPS-L1-STACK-ATBD-ARE-010166, I/R, 1/1/2
[AD7] BIOMASS L2 FD ATBD, I/R, 2/1/2
[AD8] BIOMASS L2 FH ATBD, I/R, 2/1/2
[AD9] BIOMASS L2 AGB ATBD, I/R, 3/1
[AD10] BIOMASS L2 FH PFD, BIO-BPS- FHPFD-ARE-010256, I/R, 3/0
[AD11] BIOMASS L2 AGB PFD, BIO-BPS-AGBPFD-ARE-010257, I/R, 3/0
[AD12] BIOMASS L2 FD PFD, BIO-BPS- FDPFD-ARE-010258, I/R, 3/0
[AD13] BIOMASS L3 ATBD, BIO-BPS-L3-ATBD-CES-024913, I/R, 3/2
[AD14] BIOMASS L3 PFD, BIO-BPS-AGBPFD-CAP-010257, I/R, 3/0
[AD15] BIOMASS Production Model, BIO-ESA-EOPG-EEGS-TN-0046, issue 3.5

1.5. Reference documents

[RD1] BIO-GPP-L1PDD-GP05, BIOMASS GPP L1 Product Definition Document, I/R 1/3
[RD2] BIOMASS L2 ATBD, ARE-011567, I/R, 1/5
[RD3] BIOMASS L2 ARD, ARE-010739, I/R, 2/7

2. BIOMASS Mission Overview

The BIOMASS SAR instrument will be operated in Stripmap (SM) mode imaging three different swaths, i.e., S-1, S-2 and S-3, as depicted in the following figure.

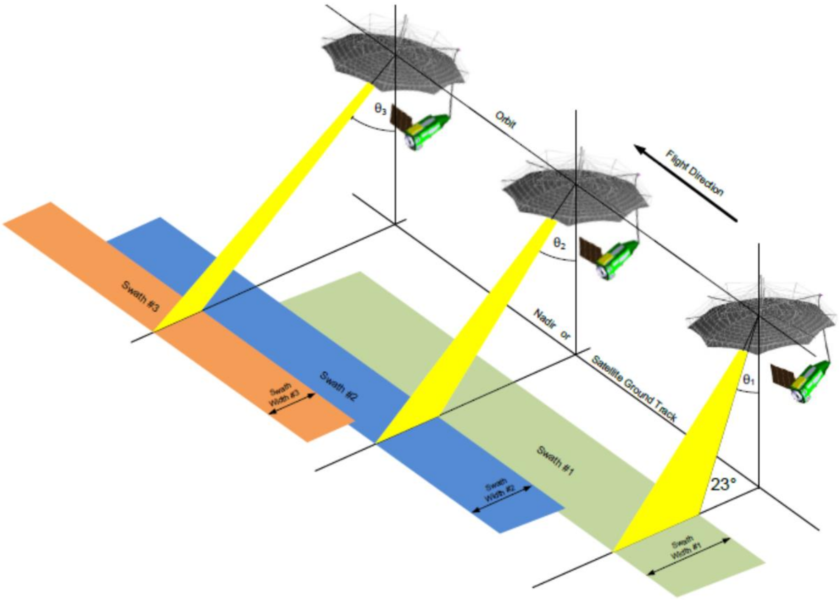


Fig.1 BIOMASS Stripmap acquisition mode.

The BIOMASS SM mode is a standard SAR Stripmap imaging mode, where the ground swath is illuminated with a continuous sequence of pulses while the antenna beam is pointing to a fixed azimuth angle and an approximately fixed off-nadir angle. This results in an image strip with continuous along-track image quality at an approximately constant incidence angle. SM can operate with one of 3 predefined elevation beams, each characterised by a different incidence angle coverage. The main parameters characterizing this mode are summarized in Sec. 4, while their dependencies on the latitude is reported in the plots of Sec. 6.

2.1. SAR Instrument Polarization Capabilities

The BIOMASS instrument is able to transmit and receive horizontal (H) and vertical (V) linear polarisations. The instrument is able to receive, on two separate receiving channels, both H and V signals simultaneously. The operational BIOMASS product is fully polarimetric, where the radar is operated by interleaving H and V polarisation signals on transmit and receiving both simultaneously. Such products are provided in the form of four images each corresponding to a different polarisation channel (HH, VV, HV or VH). The images have the similar product characteristics and are co-registered.

2.2. Attitude Steering Capabilities

The spacecraft attitude is the relative orientation of a spacecraft-fixed frame with respect to a certain flight frame of reference. The attitude can be defined by a sequence of three rotations described by the Euler angles, yaw, pitch and roll (for attitude angles definition, see for example [AD4]). The BIOMASS attitude steering has two main components, Zero-Doppler Attitude Steering and Roll Steering. These modes of operation will be described in the next two sections.

2.2.1. Zero-Doppler Attitude Steering

The BIOMASS spacecraft nominal mode of operation is the Zero-Doppler Attitude Steering Mode. The Zero-Doppler Attitude Steering law represents a significant improvement over the classical yaw-steering law designed for previous SAR missions like ERS-1/2, ENVISAT or RADARSAT-2. Due to the Earth’s rotation, the Doppler centroid, which is the Doppler frequency associated with the center of the illuminating beam on the ground, varies over the orbit; it also varies over range due to BIOMASS’s orbit inclination being different from 90º. Uncompensated variations of the Doppler centroid may cause significant, undesirable radiometric variations in the image. For cases of large Doppler centroid errors, focusing and geo-location quality may also be affected.
Similar to the yaw-steering law, the zero-Doppler steering law is a technique aimed at compensating the Doppler shift induced by Earth’s rotation. Unlike the yaw steering law, which is designed to reduce the Doppler centroid to zero at the mid-range of the swath, the Zero-Doppler Attitude Steering Law is designed to reduce the Doppler centroid to a theoretical 0 Hz, independent of the range position of interest. This is achieved by combining the yaw-steering with an additional pitch-steering. In this way, residual errors are only due to pointing inaccuracy, orbit variation errors, variations in terrain height or implementation approximations. The Zero-Doppler Attitude Steering law has a number of notable advantages with bearing on the BIOMASS Level 1 products and potential applications quality. The low residual Doppler centroid and the reduced variation of the Doppler centroid over range allow:

- More accurate Doppler centroid estimation and therefore more precise azimuth antenna pattern compensation;
- Optimized overlap of the azimuth spectra of SAR image pairs for cross-track interferometry;
- Reduced susceptibility to range dependent interferometric phase bias caused by a misregistration between the interferometric images.

2.2.2. Roll Steering

The Roll Steering Mode is a continuous maneuver around the orbit (similar to the yaw steering in azimuth) that compensates for the altitude variations, in order to minimize the updates of the PRF and sampling window position around the orbit. This allows the instrument to operate with a small fixed set of antenna beams, and simplifies the instrument operation significantly.
The roll steering law defines the roll angle (or equivalently, the off-nadir angle of pointing) of the antenna mechanical boresight versus time. The off-nadir angle is defined as a linear function of the satellite altitude. See Sec. 4 tables for angle ranges specific for each beam for the nominal altitude of 671.9 km.

2.3. Baseline Control

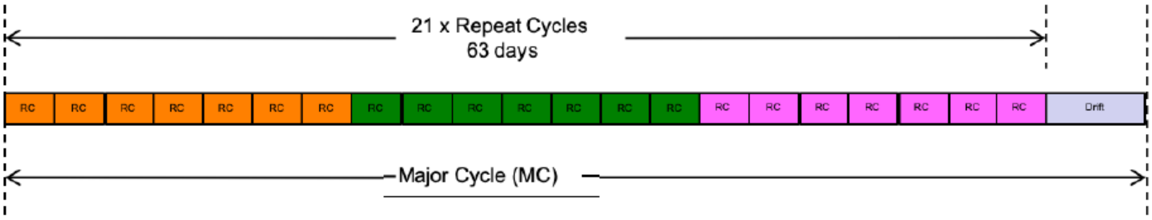
The BIOMASS satellite position is controlled such that the ground track shall be within $\pm 7.5\%$ (G) / $\pm 10\%$ (T) of the critical baseline. This requirement is necessary to avoid overlapping acquisitions during the tomographic phase, where the baseline between consecutive passes at the equator should be 15% of the critical baseline. During the interferometric phase the baseline between consecutive passes should be 30% of the critical baseline, so that the relaxed requirement of $\pm 10\%$ orbit ground track control suffices.

2.4. Coverage strategy

The system will observe during both ascending and descending passes, thus providing for each point within the observation mask at least two stacks of Level 1 data within one global coverage cycle. BIOMASS will be in a sun-synchronous orbit with a near dawn-dusk Equator crossing time (Local Time of the Ascending Node of 06:00±15 min), chosen to minimize scintillation effects that occur in the post-sunset equatorial ionosphere. The system will be left-looking and the orbit inclination will be 98°, with the highest latitude in the northern hemisphere attained on the night-side.

The BIOMASS orbital pattern will be organized into three phases:

- the 6 months Commissioning Phase (CP) is designed to allow 21 passes over a transponder at different incidence angles in order to measure the 2-D antenna pattern and test the polarimetric calibration;
- Tomographic Phase (TOM) will last approximately 17 months, Fig.2. A TOM stack will be composed of 7 acquisitions, each one separated by 3 days and a baseline of 15% of the critical baseline (approximately 0.823 km at the Equator) which will be achieved through orbital drift. The TOM phase will provide the mission's first global maps of AGB and FH. It will also give the opportunity of 3D mapping of forests;



The Tomographic Phase acquisition scheme: 1 Global Cycle, composed by 7 Major Cycles. A Major Cycle is composed by 3 Minor Cycles (21 days each, one for each of the 3 swaths, for a total of 63 days), that contain the 7 stackable SAR acquisitions, plus the Satellite Repositioning Manoeuvre (SRM).

Fig.2

- the remaining 4 years of the mission lifetime will be taken up by the Interferometric Phase (INT), Fig.3. During the INT phase each interferometric stack will consist of 3 acquisitions, thus allowing for faster global coverage. Each acquisition will be separated by 3 days and a baseline of 30% of the critical baseline.

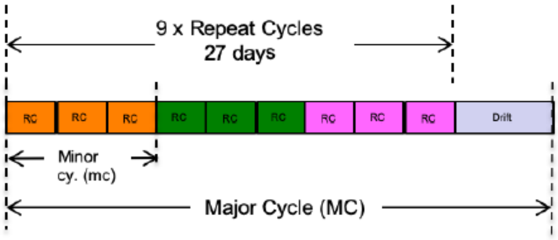


Fig.3

The Interferometric Phase acquisition scheme: 6 Global Cycles, each one composed by 7 Major Cycles. A Major Cycle is composed by 3 Minor Cycles (9 days each, one for each of the 3 swaths, for a total of 27 days), that contain the 3 stackable SAR acquisitions, plus the Satellite Repositioning Manoeuvre (SRM).

3. BIOMASS Product Family Tree

The BIOMASS Processing Suite (BPS) is in charge of processing BIOMASS Level-0 data up to Level-3, generating a wide set of products. Product generation scheme is depicted in Fig.4 for TOM phase and in Fig.5 for INT phase. The processing foresees the following steps:

- **L1 processing**: the BIOMASS image formation step;
- **Stack Processing**: the coregistration and stacking processing step that will define the required 7-images Tomographic stacks or the 3-images Interferometric stacks. It includes stack phase calibration;
- **L2a Processing**: processing step for each stack that provides the inputs to the further products Tile Generation performed by the L2b processors. For one GC the number of stacks varies mainly with latitude, approximately from a minimum of two at the Equator (ascending/descending) to about six at higher latitudes (three ascending/descending pairs). As the processing at this level is done for each stack independently, it is called stack-based. L2a products are geocoded and related to forest properties;
- **L2b Processing**: processing that aggregates all the stack-based L2a products insisting on the same location on ground (Tile) in a global cycle and generates a single BIOMASS L2b product. A different number of stacks may be available for each geographic grid tile, based on swath coverage with respect to grid tiling;
- **L3 Processing**: consolidation processing removing discontinuities in L2b products and generating products on tiles of the geographic grid. Consolidation is done on Tiles.

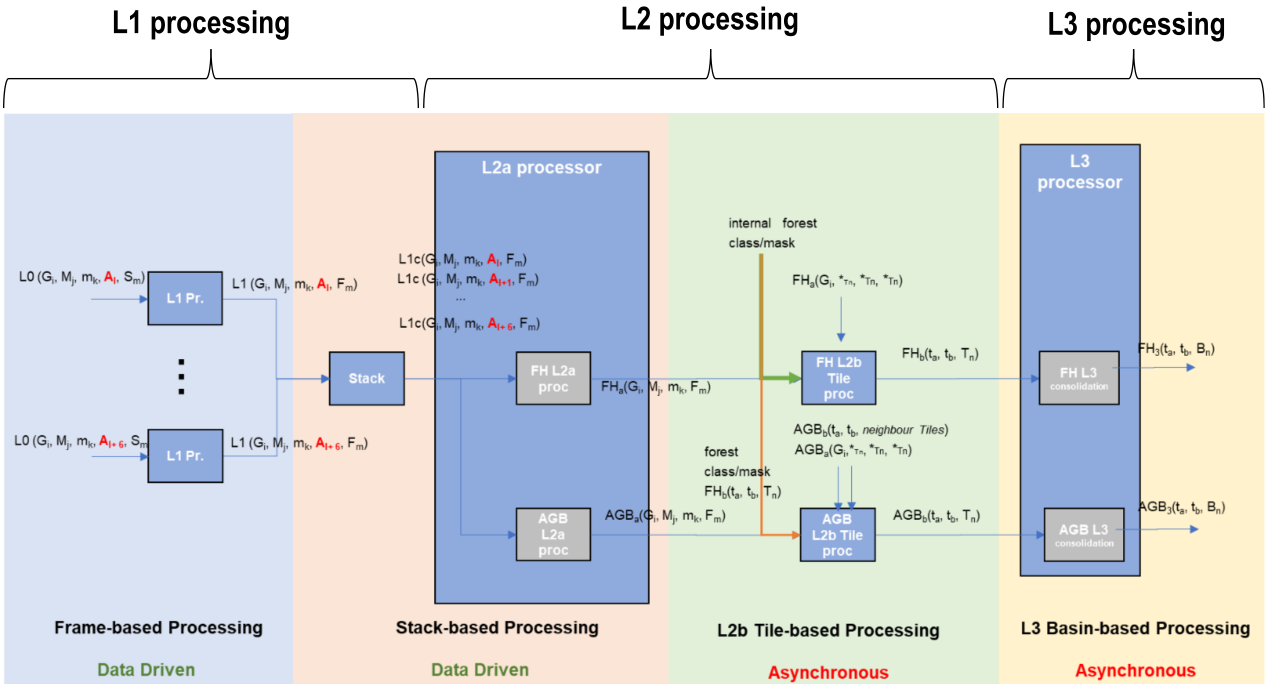


Fig.4 Biomass High-level processing scheme from L0 data to L3 products, TOM phase. Global cycle dependencies and acquisition number are highlighted.

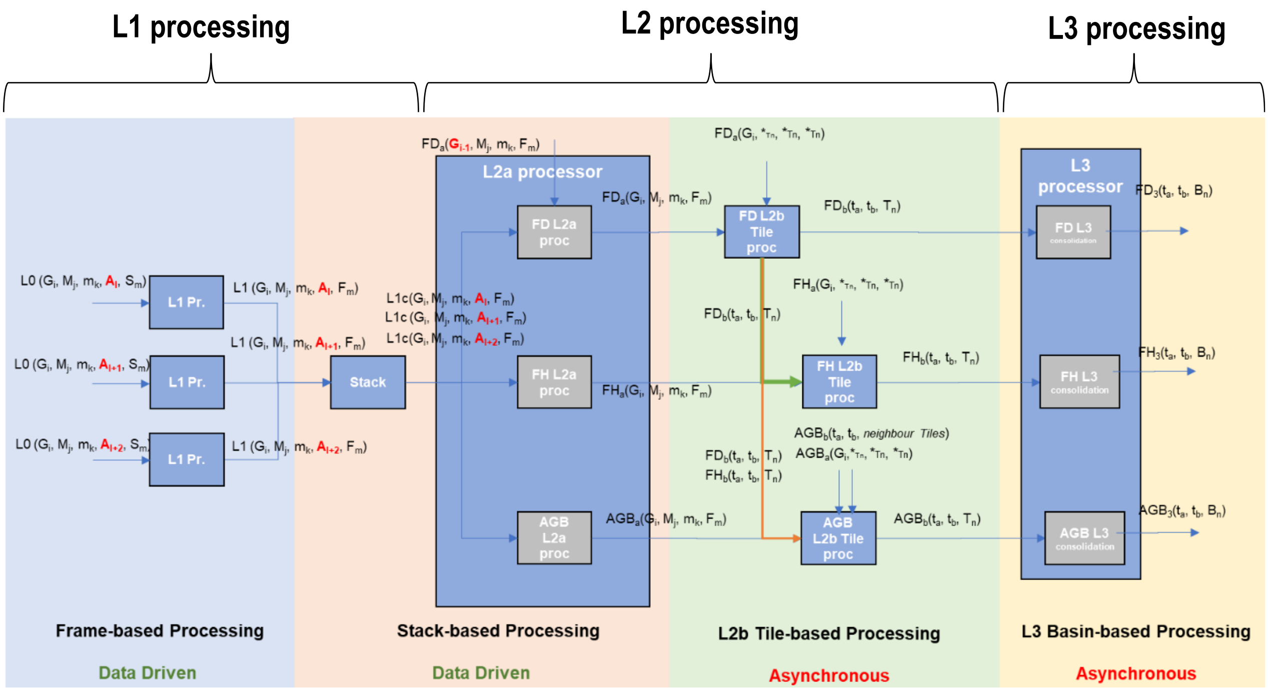


Fig.5 Biomass High-level processing scheme from L0 data to L3 products, INT phase. Global cycle dependencies and acquisition number are highlighted.

The complete BPS product family tree is presented in the following table, for all the three processing levels, giving a brief definition of each product content.

Level	BIOMASS Product Description	Products
1a	SAR focused data, internally radiometric calibrated, in zero-Doppler slant range-azimuth geometric projection, with associated ancillary data. The ionospheric corrections shall also be implemented at this level.	SCS: Single-look Complex Slant-range
	SAR focused data containing only thermal noise (no pulse transmitted, no calibration sequences), used for noise calibration.	SCS RX-Only
1b	SAR focused data radiometrically calibrated, amplitude detected, multi-looked, projected in zero-Doppler ground range-azimuth onto a reference ellipsoid resampled at a regular spacing on ground with associated ancillary data.	DGM: Detected Ground-range Multi-looked
1c	Stack products (STA), consisting of co-registered and phase calibrated SCS products based on TOM or INT sequences from the same swath and major cycle acquisitions.	STA: Coregistered Stack
2a	Stack based products related to forest properties obtained from L1c processing and auxiliary data. The retrieved parameters have a different resolution and projection (latitude-longitude) with respect to the L1c source data. In TOM and INT phases: • L2a GN for AGB: ground cancelled calibrated backscatter for all polarizations • FH: Forest Height and its quality layer. In INT phase: • FD (Forest Disturbance and probability of change maps). Optionally during TOM phase a product containing only average covariance matrix is generated.	FH: Forest Height FD: Forest Disturbance GN: Ground Cancelled Calibrated Backscatter
2b	Geophysical parameters in a geographic tile (latitude-longitude) retrieved from L2a covering the selected tile in the Global cycle: • dry weight of above-ground (living) biomass in tons/ha and its quality layer • forest top canopy height (TCH) in meters and its	AGB FH FD

Level	BIOMASS Product Description	Products
	quality layer • INT phase only: forest disturbance defined as binary classification of intact/deforested or logged areas giving indication of forest change between two global cycles, probability of change map, being the quality layer and forest mask (updated from the previous cycle) classifying the pixel as forest/non-forest, type of forest. Deforested or logged areas are defined as an area where an intact patch of forest has been cleared to zero biomass (or below the sensitivity limit for BIOMASS).	
3	Geophysical parameters consolidated on a global grid from L2b data, alleviating discontinuities.	AGB and FH, consolidated tiles

Tab.1 Product family tree.

NOTE: Regarding AGB, the nomenclature AGB L2a (AGB_a) indicates the processing unit and flow, whereas the product for AGB flow at L2a is the ground cancelled product (GN) [AD15].

The following sub-sections provide a high-level description of each product, as well as all the useful links to the applicable product documentation tree.
In the next section each product will be defined in detail, describing its performances and main parameters (resolution, coverage …).

3.1. L1 products overview

For the BIOMASS SM acquisition mode, the following types of L1 products are defined:

- L1a or Single-look Complex Slant-range (SCS);
- L1b or Detected Ground-range Multi-looked (DGM);
- L1c or Coregistered Stack (STA).

The following table presents the main properties of such products. These parameters are a subset of those explained in details in Sec. 4.

Acq Mode	Product Type	Resolution [Rg x Az] [m]	Pixel Spacing [Rg x Az] [m]	No. Looks [Rg x Az]	ENL
SM	SCS	22,8 x 7,6 to 23,5 x 7,9	19,8 x 6,7	1 x 1	1
	DGM	53,4 x 50,5	25 x 25	1 x 6	6

Acq Mode	Product Type	Resolution [Rg x Az] [m]	Pixel Spacing [Rg x Az] [m]	No. Looks [Rg x Az]	ENL
		to 54,4 x 50,5			
	STA	as SCS	as SCS	as SCS	as SCS

Tab.2 BIOMASS L1 products overview.

All the L1 products are defined on a frame basis. The framing strategy is based on a fixed a priori OPS angle-based grid (OPS angle is the angle given by ANX, Earth centre and satellite) that is used to compute frame start and stop times. The nominal frame length is of about 21s (as reported in the tables in Sec. 4). In general, is then possible to have frames with length different from nominal one (i.e., 21s), even if expected differences are in the order of few seconds.

L1a or Single-look Complex Slant-range (SCS)

L1a products are images in the slant range by azimuth imaging plane, in the image plane of satellite data acquisition. Each image pixel is represented by a complex (amplitude and phase) value containing calibrated radar brightness. The processing for all L1a products results in a single look in each dimension using the full available signal bandwidth. The imagery is geo-referenced using orbit and attitude data from the satellite. L1a images are produced in a Zero Doppler geometry. This convention is common with the standard slant range products available from other SAR sensors (e.g., ERS-1/2, ENVISAT/ASAR, RADARSAT-1/2, Sentinel-1, TerraSAR-X). The L1a products contain one image per polarisation channel. The L1a image is sampled at the natural pixel spacing in range (i.e., the radar range sampling frequency) and at a configurable pixel spacing in azimuth (lower than PRF, see Sec. 4.1). This is achieved through a resampling along azimuth direction, which allows also to manage PRF changes during acquisition.
Default correction applied to L1a data are:

- RAW data correction;
- RFI mitigation;
- Internal calibration corrections;
- Antenna pattern and antenna cross-talk corrections;
- Azimuth bistatic delay correction;
- Radiometric corrections (range spread loss, processing gain, absolute calibration constant);
- Polarimetric corrections (cross-talk, channel imbalance);
- Ionospheric corrections;

while autofocus is not applied by default.
The detailed definition of L1a products is provided in Sec. 4.1.1.

Note: SCS RX-Only share the same characteristics of SCS products. In particular, they follow the same acquisition timeline of S1 beam, with the difference that no pulses are transmitted (then only thermal noise is received, and from here the name) and no calibration sequences are stored (neither in the pre/postamble nor interleaved).

L1b or Detected Ground-range Multi-looked (DGM)

L1b products lie in the ground range by azimuth surface, with image coordinates oriented along ground range and flight direction. The standard L1b products are detected, multi-look products, with approximately square resolution cells and square pixel spacing. Each image pixel is represented by a real (amplitude) value containing calibrated radar brightness. Multi-looking is a processing property that results in images with reduced speckle, but also with reduced resolution: the more looks the less speckle noise and the lower the resolution. To convert from imaging slant range coordinates to ground range coordinates, a slant to ground projection is performed onto an ellipsoid (typically the WGS84 ellipsoid). L1b images are produced in a Zero Doppler geometry.

Default correction applied to L1b data are the same of L1a ones. Denoising is not applied by default on data.

The detailed definition of L1b products is provided in Sec. 0.

L1c or Coregistered Stack (STA)

BIOMASS L1c products are obtained coregistering a given L1a image over another reference L1a image. The coregistration operation consists in a bidimensional interpolation of the data over a reference sampling grid, then from the point of view of product definition parameters a L1c product is identical to a L1a one. The only exception is the number of polarizations, which can be either 4 or just 3 (the two co-polarizations plus a combination of the two cross-polarizations). Each L1c product contains just one image. The term ‘stack’ is used to indicate a set of L1c products (3 for INT phase, 7 for TOM phase) generated using the same reference image and just logically linked. Reference image is selected in the following way:

- for the coregistration step, as the image with median baseline in the stack, discarding those images not at sufficient quality at L1 level in terms of RFI mitigation and ionospheric correction;
- for the correction steps, as the image with the best quality at L1 level in terms of RFI mitigation and ionospheric correction.

Default correction applied to L1c data are:

- common band azimuth filtering;
- azimuth residual shifts correction based on split bandwidth interferometry;
- slow-varying and fast-varying ionosphere corrections (always applied or applied basing on latitude, depending on processing configuration).

Phase screen, based on Sum of Kronecker Product (SKP) decomposition, is estimated but not applied by default for calibration.

The detailed definition of L1c products is provided in Sec. 0.

3.2. L2 products overview

NOTE: actual parameters are under review and will evolve with next document versions.

L2 products are derived by processing L1c products to generate quantities related to forest properties. L2 products are internal products generated only for the BIOMASS scientific team. They can be divided into:

- L2a stack-based: these geocoded products are obtained by processing an entire L1c stack (TOM or INT) and have the same L1 frame coverage projected onto a Discrete Global Grid for forest products (they are not cut into tiles). L2a lie on the same sampling grid as L2b/L3;
- L2b tile-based: these products are obtained by processing all L2a products relative to a specific geographic DGG tile in the Global cycle.

The concept is illustrated in Fig.6.

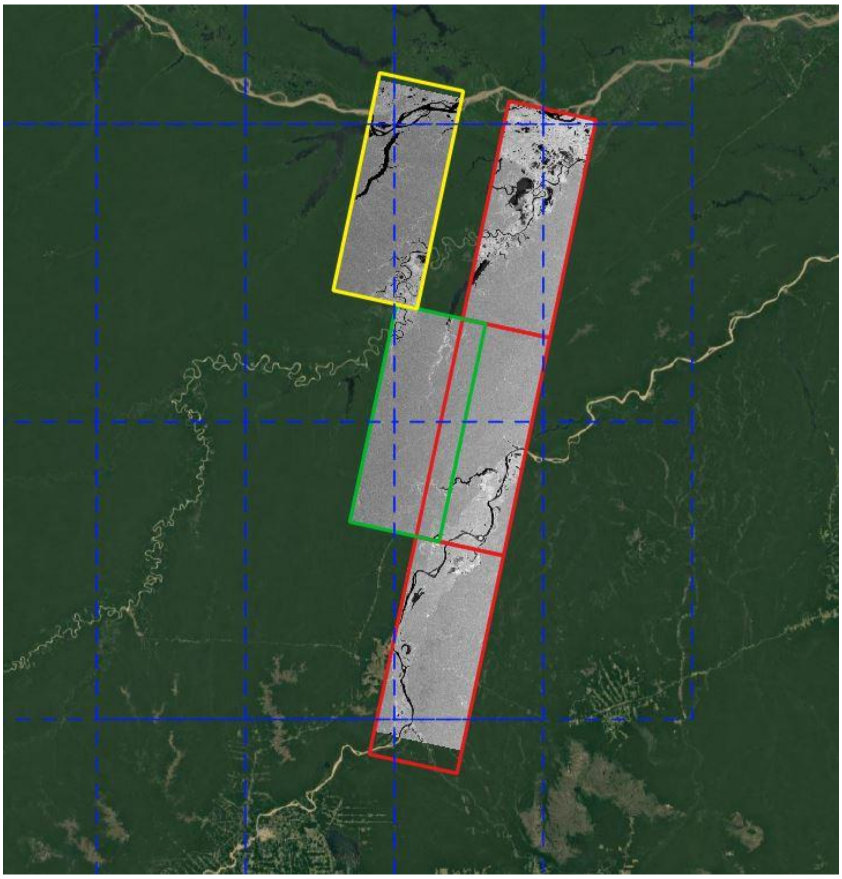


Fig.6

Example of L2a products (red, green yellow boxes), with swath coverage projected onto geographic grid and geographic grid tiles (dotted blue boxes).

L2a (Stack Based)

Product Type	Resolution [m]	Pixel Spacing [lat x lon]	No. Looks [Rg x Az]	ENL
GN	100	1.5” x 1.5” to 1.5” x 3”	2 x 12	24
FH	200	3” x 3” to 3” x 6”	4 x 25	100
FD	50	1.5” x 1.5” to 1.5” x 3”	1 x 6	6

NOTE: Pixel Spacing values are latitude-dependant. In this table interval extremes are reported, while detailed values are reported in Sec. 4.2.

Tab.3 BIOMASS L2a products overview.

The Level 2a processing is responsible for the generation of stack based products related to forest properties. Each pixel of these products can be considered independently, as resulting from multi-looking, and perfectly localised in time and space. At this level there is no dependency between different L2a products and this part can be thought of a biophysical processing extension to the stack processor (L1c). The products are geocoded:

- FD: the Forest Disturbance Level 2a product, giving indication of forest change between two global cycles, probability of change, being the quality layer and classification of pixels into forest/non-forest;
- FH: Forest Height L2a product, representing top canopy height. Same algorithms are envisaged to generate the same product in INT and TOM phases;
- GN: Above Ground Biomass L2a processing product. This product corresponds to ground cancelled data, enhancing volume contribution, to be input to L2b for AGB generation. Same algorithms are envisaged to generate the same product in INT and TOM phases.

The detailed definition of L2a products is provided in 4.2.1.

L2b (Tile Based)

Product Type	Resolution [m]	Pixel Spacing [lat x lon]
AGB	200	3” x 3” to 3” x 6”
FH	200	3” x 3” to 3” x 6”
FD	50	1.5” x 1.5” to 1.5” x 3”

NOTE: Pixel Spacing values are latitude-dependant. In this table interval extremes are reported, while detailed values are reported in Sec. 4.2.

Tab.4 BIOMASS L2b products overview.

L2b products are geophysical, on map and tile based, derived from merging (based on L2a quality or information) all L2a in a given Global cycle on the tile. The products at this level can take advantage of FD availability (for the same geographic tile) or of a forest mask generated outside of BPS [AD15], to mask out non-forest pixels. The products are:

- FD: The Forest Disturbance level 2b product;
- FH: The Forest Height level 2b product;
- AGB: Above Ground Biomass level 2b product.

The detailed definition of L2b products is provided in 0.

3.2.1. Discrete Global Grid (DGG) for forest products

DGG tiles have a dimension of 1°x1° in latitude-longitude, coverage is global excluding the Space Object Tracking Radars area and areas over 70° (both N and S).

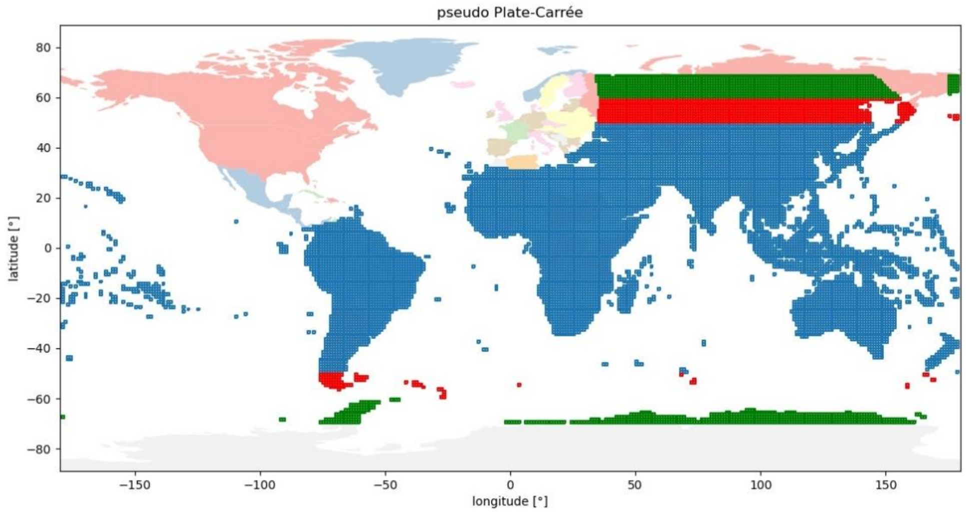


Fig.7 Discrete Global Grid (DGG) for forest products.

Two additional latitudinal bands are highlighted in red and green, in addition to the central one between 50°S and 50°N in blue. Red band is between 50°-60° N and S, with sampling 1.5 times lower than sampling in blue band and green band is between 60°-70° N and S, with sampling lower 2 times than in blue band, to cope with the convergence of meridians at higher latitude. To guarantee sampling requirements, it is defined to have two sampling levels: a spatial spacing smaller than 50m for FD and better than 100m for AGB and FH products. The oversampling by 2 of AGB and FH quantities aims to better account for smooth variations of these continuous estimates. The number of grid pixels per tile is equal to the number of intervals per tile plus one. As a consequence, overlapping pixels (in both directions) of adjacent tiles have identical content, except in latitude in the case of a change of the longitude grid spacing between adjacent tiles (change of latitude band). Previous information is summarized in Tab.5, Tab.6.

Latitude (N and S)	Latitude spacing	Longitude spacing	Dimensions of a 1ºx1º tile (Nr x Nc)
0º - 50º	3” (≈ 92.8m)	3” (≈ 92.8m – 59.7m)	(1201 x 1201)
50º – 60º	3” (≈ 92.8m)	4.5” (≈ 89.6m – 69.8m)	(1201 x 801)
60º – 70º	3” (≈ 92.8m)	6” (≈ 93m – 63.6m)	(1201 x 601)

Tab.5 Pixel spacing in arc seconds (“) and meter (m) for the AGB and FH products. Longitude spacings are given at the beginning and final coordinates of 3 latitude domains per hemisphere. The dimensions of a 1ºx1º tile are given in pixels.

Latitude (N and S)	Latitude spacing	Longitude spacing	Dimensions of a 1ºx1º tile (Nr x Nc)
0º - 50º	1.5” (≈ 46.4m)	1.5” (≈ 46.4m – 29.9m)	(2401 x 2401)
50º – 60º	1.5” (≈ 46.4m)	2.25” (≈ 44.8m – 34.9m)	(2401 x 1601)
60º – 70º	1.5” (≈ 46.4m)	3” (≈ 46.5m – 31.8m)	(2401 x 1201)

Tab.6 Pixel spacing in arc seconds (“) and meter (m) for the FD products. Longitude spacings are given at the beginning and final coordinates of 3 latitude domains per hemisphere. The dimensions of a 1ºx1º tile are given in pixels.

NOTE: actual parameters are under review and will evolve with next document versions.

3.3. L3 products overview

Product Type	Resolution [m]	Pixel Spacing [lat x lon]
AGB	200	3” x 3” to 3” x 6”

Product Type	Resolution [m]	Pixel Spacing [lat x lon]
FH	200	3” x 3” to 3” x 6”

NOTE: Pixel Spacing values are latitude-dependant. In this table interval extremes are reported, while detailed values are reported in Sec. 4.2.

Tab.7 BIOMASS L3 products overview.

Level 3 products are consolidated products for a specific tile, in a Global cycle.. The products are:

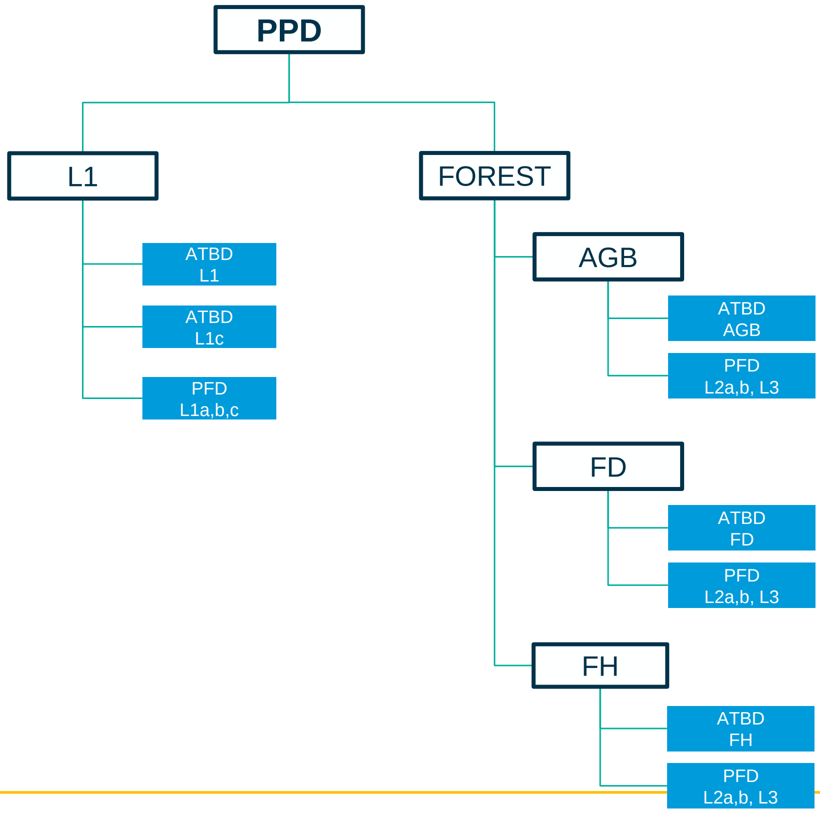
- FH: The Forest Height level 3 product;
- AGB: The Above Ground Biomass level 3 product.

The detailed definition of L3 products is provided in Sec. 4.2.

3.4. Product documentation tree

The current document works as a top level one in the BIOMASS product documentation tree, being the entry point for all the other documents which can be seen as sub-documents and are maintained by separated branches (i.e., L1 and Forest).

The complete documentation tree is depicted in the following figure, distinguishing between branches, product types (L1, AGB, FD, FH) and document types (ATBD, PFD).



Product documentation tree.

All the documents listed in the above tree will be generated and maintained during the whole BPS project lifetime. Here below the full list with the specific codes and with the links to Applicable Documents (AD) section where already available:

Fig.8

Doc. Family	Doc. Type	Doc. Code	Description	Ref.
L1	ATBD L1	**BPS_L1_SAR_ATBD**	BIOMASS L1 SAR product ATBD	[AD5]
	ATBD L1c	**BPS_L1_STACK_ATBD**	BIOMASS L1c Stack product ATBD	[AD6]
	PFD L1a,b,c	**BPS_L1_PFD**	BIOMASS L1a,b,c products format specification	[AD1]
Forest AGB	ATBD AGB	**BPS_AGB_ATBD**	BIOMASS Above Ground Biomass ATBD	[AD9]
	PFD L2a,b,	**BPS_AGB_PFD**	BIOMASS AGB L2a,b products format specification	[AD11]
	PFD L3	**BPS_L3_PFD**	BIOMASS AGB L3 products format specification	[AD14]
Forest FD	ATBD FD	**BPS_FD_ATBD**	BIOMASS Forest Disturbance ATBD	[AD7]
	PFD L2a,b,	**BPS_FD_PFD**	BIOMASS FD L2a,b and L3 products format specification	[AD12]
Forest FH	ATBD FH	**BPS_FH_ATBD**	BIOMASS Forest Height ATBD	[AD8]
	PFD L2a,b,	**BPS_FH_PFD**	BIOMASS FH L2a,b products format specification	[AD10]
	PFD L3	**BPS_L3_PFD**	BIOMASS FH L3 products format specification	[AD14]

Tab.8 Product documentation tree.

4. BIOMASS Product Definition

This section provides the detailed characteristics of the standard BIOMASS L1, L2 and L3 products. In particular, for each product, tables are used to summarize:

- main product characteristics;
- most relevant product performance parameters;
- SAR processing parameters having a direct impact on these values;
- data sizes and volumes for typical products.

Descriptions of the terms used in the product definition tables are given in Sec. 5. Complete product format, including annotations/auxiliary layers is given in PFD documents, as described in Sec. 3.4.

Numbers reported in this section have been computed starting from constants and reference values reported in the following table and from round-orbit parameters analysis outcome presented in Sec. 6.

System Parameter	Value
Carrier frequency [MHz]	435
Lambda [m]	0,689
Ground velocity [m/s] (average value at mid-swath mid-range)	6835
Range sampling frequency [Hz]	7565217,4
Doppler Centroid [Hz]	0
Azimuth processing bandwidth [Hz]	849,0
Terrain height [m]	0

Tab.9 Constants and reference values used for the computation of BIOMASS products definition parameters.

Considering that values for INT and TOM phases have proven to be really similar (see Sec. 6), INT one has been taken as reference for the computation of parameters shown in product definition tables. In particular, two “boundary” cases have been considered, i.e., Equator and South Pole. The corresponding parameters, taken from BIOMASS Instrument RDB [AD2], are summarised in the following table.

System Parameter		Value		
Beam ID		**S1**	**S2**	**S3**
Equator	TXPL [µs]	41,16	47,00	50,28
	PRI [µs]	316,82	325,86	335,38
	SWP [µs]	74,71	60,04	64,37
	SWL [µs]	228,28	262,52	256,57
South Pole	TXPL [µs]	41,16	47,00	50,28
	PRI [µs]	322,21	325,86	335,38
	SWP [µs]	158,81	93,24	82,11
	SWL [µs]	159,94	229,07	221,94

Tab.10 Reference parameters taken from BIOMASS Instrument RDB.

4.1. L1 products definition

Note that for the definition of BIOMASS L1 products [RD1] has been used as reference and starting point. Values have then been updated considering parameters listed in Sec. 4 and missing information (data sizes and volumes, …) have been computed accordingly.

4.1.1. L1a product definition

Product ID	**SM_SCS**		
Product Type	Stripmap, Slant Range, Single Look, Complex		
Main Product Characteristics			
Pixel Value	Complex (Amplitude, proportional to calibrated radar brightness, and Phase)		
Coordinate System	Slant Range		
Bits Per Pixel	64 (32 Amplitude + 32 Phase)		
Polarization Options	Full (HH, HV, VH, VV)		
Beam ID	**S1**	**S2**	**S3**
Ground Range Coverage [km]	44 km - 67 km (latitude dependent)		
Equator	65,07	66,74	58,25
South Pole	43,86	65,91	55,23
Slant Range Resolution [m]	22,80	23,46	23,46
Azimuth Resolution [m]	7,92	7,92	7,56
Slant Range Pixel Spacing [m]	19,81		
Azimuth Pixel Spacing [m]	6,71		
Incidence Angle (@ mid-swath) [deg] Equator	25,51	28,92	32,04
South Pole	23,91	24,40	27,72
Equivalent Number of Looks (ENL)	1		
Radiometric Resolution [dB]	3		
Product Performance Parameters (see Sec. 5.1)			
Range PSLR [dB]	-16 ± 2		
Azimuth PSLR [dB]	-16 ± 2		
2D ISLR [dB]	-9 ± 0,5		
Total Ambiguity Ratio [dB]	<-18		
NESZ [dB]	<-28		
Channel Co-registration Accuracy [pixels]	better than 1/100 of a pixel		
Radiometric Bias [dB] (1 sigma)	0,3		
Radiometric Stability [dB] (1 sigma)	0,5		
Absolute Location Accuracy [m]	25 @ 3-sigma		
SAR Processing Parameters			
Number of Looks (range x azimuth)	1 x 1		

Look Overlap (range x azimuth)	N/A		
Range Look Bandwidth [MHz]	6,0		
Azimuth Look Bandwidth [Hz]	849,0		
Range Hamming Weighting Coefficient	0,91	0,86	0,86
Azimuth Hamming Weighting Coefficient	0,77	0,78	0,86
Data Size & Volume for a Nominal Frame (21-second Long) @ Equator			
Approx. # of Lines	21395	21395	21395
Approx. # of Pixels per Line	1416	1631	1561
Max Data Volume (Single Polarization) [MB]	232	267	255
Max Data Volume (Full Polarization) [MB]	928	1068	1020
Max Data Volume (Full Polarization, Final Format) [MB]	564	634	610
Average Data Rate [MB/s]	27	30	29
Data Size & Volume for a Nominal Frame (21-second Long) @ South Pole			
Approx. # of Lines	21395	21395	21395
Approx. # of Pixels per Line	899	1378	1299
Max Data Volume (Single Polarization) [MB]	147	225	213
Max Data Volume (Full Polarization) [MB]	588	900	852
Max Data Volume (Full Polarization, Final Format) [MB]	394	550	526
Average Data Rate [MB/s]	19	26	25

Tab.11 L1a (SCS) product definition table.

Notes:

- for the computation of data sizes and volumes a typical L1 frame of 21 seconds has been considered;
- along azimuth direction, a down-sampling w.r.t. the original PRF has been considered (in particular, up to the processing bandwidth + 20%);
- volumes are indicated in two “versions”: referred to the SAR image binary data only and considering no compression applied to GeoTIFF files (i.e., 32+32 bits for amplitude and phase components); referred to the complete L1a product, including compressed GeoTIFF files for binary data, with overviews, and annotations, including LUTs. For all the details on L1a products format and applied compression strategies refer to [AD1].

4.1.2. L1b product definition

Product ID	**SM_DGM**		
Product Type	Stripmap, Ground Range, Multi Look, Detected		
Main Product Characteristics			
Pixel Value	Real (Amplitude, proportional to calibrated radar brightness)		
Coordinate System	Ground Range		
Bits Per Pixel	32		
Polarization Options	Full (HH, HV, VH, VV)		
Beam ID	**S1**	**S2**	**S3**
Ground Range Coverage [km]	44 km - 67 km (latitude dependent)		
Equator	65,07	66,74	58,25
South Pole	43,86	65,91	55,23
Ground Range Resolution [m]	53,45	54,40	54,23
Azimuth Resolution [m]	50,49	50,49	50,49
Ground Range Pixel Spacing [m]	25		
Azimuth Pixel Spacing [m]	25		
Incidence Angle (@ mid-swath) [deg] Equator	25,51	28,92	32,04
South Pole	23,91	24,40	27,72
Equivalent Number of Looks (ENL)	6		
Radiometric Resolution [dB]	1,48		
Product Performance Parameters (see Sec. 5.1)			
Range PSLR [dB]	-16 ± 2		
Azimuth PSLR [dB]	-16 ± 2		
2D ISLR [dB]	-9 ± 0,5		
Total Ambiguity Ratio [dB]	<-18		
NESZ [dB]	<-28		
Channel Co-registration Accuracy [pixels]	better than 1/100 of a pixel		
Radiometric Bias [dB] (1 sigma)	0,3		
Radiometric Stability [dB] (1 sigma)	0,5		
Absolute Location Accuracy [m]	25 @ 3-sigma		
SAR Processing Parameters			
Number of Looks (range x azimuth)	1 x 6		
Look Overlap (range x azimuth)	0 x 0		
Range Look Bandwidth [MHz]	6,00	5,25	4,80
Azimuth Look Bandwidth [Hz]	141,50	141,50	141,50
Range Hamming Weighting Coefficient	0,90	0,90	0,90
Azimuth Hamming Weighting Coefficient	0,70	0,70	0,70
Data Size & Volume for a Nominal Frame (21-second Long) @ Equator			

Approx. # of Lines	5741	5741	5741
Approx. # of Pixels per Line	2603	2670	2330
Max Data Volume (Single Polarization) [MB]	58	59	52
Max Data Volume (Full Polarization) [MB]	232	236	208
Max Data Volume (Full Polarization, Final Format) [MB]	255	257	239
Average Data Rate [MB/s]	12	12	11
Data Size & Volume for a Nominal Frame (21-second Long) @ South Pole			
Approx. # of Lines	5741	5741	5741
Approx. # of Pixels per Line	1754	2636	2209
Max Data Volume (Single Polarization) [MB]	39	58	49
Max Data Volume (Full Polarization) [MB]	156	232	196
Max Data Volume (Full Polarization, Final Format) [MB]	204	255	231
Average Data Rate [MB/s]	10	12	11

Tab.12 L1b (DGM) product definition table.

Notes:

- range and azimuth pixel spacing values have been computed considering nearly half the resolution values in both directions, to take into account effects of detection operation on data spectrum;
- range and azimuth bandwidths and weighting coefficients have been computed to achieve the same resolution in both directions for all the three beams (i.e., 55x50m);
- for the computation of data sizes and volumes a typical L1 frame of 21 seconds has been considered;
- volumes are indicated in two “versions”: referred to the SAR image binary data only and considering no compression applied to GeoTIFF file (i.e., 32 bits for amplitude component); referred to the complete L1b product, including compressed GeoTIFF file for binary data, with overviews, and annotations, including LUTs. For all the details on L1b products format and applied compression strategies refer to [AD1].

4.1.3. L1c product definition

Product ID	**SM_STA**		
Product Type	Stripmap, Slant Range, Single Look, Complex		
Main Product Characteristics			
Pixel Value	Complex (Amplitude, proportional to calibrated radar brightness, and Phase)		
Coordinate System	Slant Range		
Bits Per Pixel	64 (32 Amplitude + 32 Phase)		
Polarization Options	Full (HH, HV, VH, VV)		
Beam ID	**S1**	**S2**	**S3**
Ground Range Coverage [km]	44 km - 67 km (latitude dependent)		
Equator	65,07	66,74	58,25
South Pole	43,86	65,91	55,23
Slant Range Resolution [m]	22,80	23,46	23,46
Azimuth Resolution [m]	7,92	7,92	7,56
Slant Range Pixel Spacing [m]	19,81		
Azimuth Pixel Spacing [m]	6,71		
Incidence Angle (@ mid-swath) [deg] Equator	25,51	28,92	32,04
South Pole	23,91	24,40	27,72
Equivalent Number of Looks (ENL)	1		
Radiometric Resolution [dB]	3		
Product Performance Parameters (see Sec. 5.1)			
L1a Product Performance Parameters	preserved		
Coregistration accuracy	< 1/10 resolution cell		
Decorrelation factor	> 0.95		
SAR Processing Parameters			
Number of Looks (range x azimuth)	1 x 1		
Look Overlap (range x azimuth)	N/A		
Range Look Bandwidth [MHz]	6,0		
Azimuth Look Bandwidth [Hz]	849,0		
Range Hamming Weighting Coefficient	0,91	0,86	0,86
Azimuth Hamming Weighting Coefficient	0,77	0,78	0,86
Data Size & Volume for a Nominal Frame (21-second Long) @ Equator			
Approx. # of Lines	21395	21395	21395
Approx. # of Pixels per Line	1416	1631	1561
Max Data Volume (Single Polarization) [MB]	232	267	255
Max Data Volume (3 Polarizations) [MB]	696	801	765
Max Data Volume (3 Polarizations, Final Format) [MB]	448	501	483
Average Data Rate [MB/s]	21	24	23

Max Data Volume (4 Polarizations) [MB]	928	1068	1020
Max Data Volume (4 Polarizations, Final Format) [MB]	564	634	610
Average Data Rate [MB/s]	27	30	29
Data Size & Volume for a Nominal Frame (21-second Long) @ South Pole			
Approx. # of Lines	21395	21395	21395
Approx. # of Pixels per Line	899	1378	1299
Max Data Volume (Single Polarization) [MB]	147	225	213
Max Data Volume (3 Polarizations) [MB]	441	675	639
Max Data Volume (3 Polarizations, Final Format) [MB]	321	438	420
Average Data Rate [MB/s]	15	21	20
Max Data Volume (4 Polarizations) [MB]	588	900	852
Max Data Volume (4 Polarizations, Final Format) [MB]	394	550	526
Average Data Rate [MB/s]	19	26	25

Tab.13 L1c (STA) product definition table.

Notes:

- for the computation of data sizes and volumes a typical L1 frame of 21 seconds has been considered;
- along azimuth direction, a down-sampling w.r.t. the original PRF has been considered (in particular, up to the processing bandwidth + 20%);
- volumes have been computed considering both the cases of 3 or 4 polarizations;
- volumes are indicated in two “versions”: referred to the SAR image binary data only and considering no compression applied to GeoTIFF files (i.e., 32+32 bits for amplitude and phase components); referred to the complete L1c product, including compressed GeoTIFF files for binary data, with overviews, and annotations, including LUTs. For all the details on L1c products format and applied compression strategies refer to [AD1].

4.2. L2 and L3 products definition

NOTE: actual parameters are under review and will evolve with next document versions.
Note that for the definition of BIOMASS L2 products [RD2], [RD3] have been used as reference and starting point. Numbers are indicative of the current status of L2. L2 products are internal products generated only for the BIOMASS scientific team.

4.2.1. L2a intermediate product definition

Product ID	**FD_L2a**	**FH_L2a**	**GN_L2a**
Product Type	Stack based, Geocoded, Multi-look, Integer and Real	Stack based, Geocoded, Multi-look, Real	Stack based, Geocoded, Multi-look, Real
Main Product Characteristics			
Pixel Value	Forest disturbance (integer) Probability of change (real) Computed forest mask (integer)	Forest height and quality	Ground cancelled calibrated back-scatter (HH/VH/ VV)
Coordinate System	DGG		
Bits Per Pixel	8 (forest disturbance and mask) 32 (probability of change)	32	32
Number of layers	3	2	3
Azimuth coverage [km]	150		
Ground Range Coverage [km]	36 km - 65 km (latitude dependent)		
Resolution on map [m]	50	200	100
Pixel spacing on map	(Latitude and product dependent)		
50° S - 50° N	1.5” x 1.5”	3” x 3”	1.5” x 1.5”
50° S - 60° S 50° N - 60° N	1.5” x 2.25”	3” x 4.5”	1.5” x 2.25”
60° S - 70° S 60° N - 70° N	1.5” x 3”	3” x 6”	1.5” x 3”
Temporal coverage	21 days (TOM) 9 days (INT)		
Number of looks	6	100	24
Data Size & Volume @ Equator			
Approx. # of Lines	3319	1660	3319
Approx. # of Pixels per Line	1401	701	1401
Max Data Volume [MB]	27	9	53
Max Data Volume (Final Format) [MB]	98	5	38
Data Size & Volume @ 70°			
Approx. # of Lines	3319	1660	3319
Approx. # of Pixels per Line	776	388	776
Max Data Volume [MB]	15	5	29
Max Data Volume (Final Format) [MB]	54	3	21

Tab.14 L2a intermediate products definition table.

Notes:

- pixel spacing values have been computed considering nearly half the resolution values in both directions, to take into account effects of detection operation on data spectrum, except for FD, which is a mask;
- for the computation of data sizes minimum and maximum coverage numbers have been assumed, however L2a products have the same beam dependency as L1;
- the “boundary” case South Pole of L1 has been rescaled to 70°, as DGG products are limited there;
- data size have been computed neglecting the small orbit inclination. This would cause an increase of about 36% due to empty pixels needed to accommodate for that. However, by using a compression scheme this increase would have a minimal impact on the final volume, thus negligible;
- L2a GN has twice the resolution of L2b/L3 AGB product to accommodate for processing needed for AGB generation;
- GeoTIFF format is recommended over NetCDF;
- L2a FD is computed relying on an Average Covariance Matrix object, representing the history of previous global cycles. This object is a state variable accounting for three real and three complex images representing a Hermitian covariance matrix, with the same coverage and sampling as FD product. It is stored within the annotation folder of the folder-based product as documented in the correspondent PFD [AD12]. For this Average Covariance Matrix object NetCDF format is used;
- volumes are indicated in two “versions”: referred to binary data only and considering no compression applied to GeoTIFF files (32 bits for float, 8 bits for integer components); referred to the complete L2a product, including compressed GeoTIFF files for binary data and annotations, including LUTs with compression for NetCDF. For all the details on L2 products format and applied compression strategies refer to [AD1][AD10][AD11][AD12].

4.2.2. Forest Disturbance

Product ID	**FD_L2b**
Product Type	L2b: Tile based, Geocoded, Multi-stack, Integer and real
Main Product Characteristics	
Pixel Value	Forest disturbance, computed forest mask, probability of change.
Coordinate System	DGG
Bits Per Pixel	8 (forest disturbance) 8 (computed forest mask) 32 (probability of change)
Number of layers	3
Coverage on map	1° x 1°
Resolution on map [m]	50
Pixel spacing on map	
50° S - 50° N	1.5” x 1.5”
50° S - 60° S 50° N - 60° N	1.5” x 2.25”
60° S - 70° S 60° N - 70° N	1.5” x 3”
Temporal coverage	Inherited from processed L2a within global cycle
Product accuracy	0.01 (detection significance level)
Data Size	
Approx. # of Latitude Samples	2401
Approx. # of Longitude Samples	
50° S - 50° N	2401
50° S - 60° S 50° N - 60° N	1601
60° S - 70° S 60° N - 70° N	1201
Max Data Volume [MB]	(full tile coverage)
50° S - 50° N	33
50° S - 60° S 50° N - 60° N	22
60° S - 70° S 60° N - 70° N	17
Max Data Volume (Final Format) [MB]	(full tile coverage)
50° S - 50° N	19
50° S - 60° S 50° N - 60° N	13
60° S - 70° S 60° N - 70° N	10

Tab.15 L2b/L3 Forest Disturbance product definition table.

Notes:

- for the computation of data sizes indicative numbers from [AD15] subject to review;
- pixel spacing values have been computed considering the resolution values in both directions, considering the information of FD is of masking type;
- volumes are indicated in two “versions”: referred to binary data only and considering no compression applied to GeoTIFF files (32 bits for float, 8 bits for integer components); referred to the complete L2b FD product included the Heat Map [AD12] and consisting in compressed GeoTIFF files for binary data. For all the details on L2b FD product format and applied compression strategies refer to [AD1][AD12].
- GeoTIFF format is recommended over NetCDF.

4.2.3. Forest Height

Product ID	**FH_L2b/FH_L3**
Product Type	L2b: Tile based, Geocoded, Multi-stack, Real L3: Tile based, Geocoded, Multi-stack, Real
Main Product Characteristics	
Pixel Value	Forest height, quality, forest mask
Coordinate System	DGG
Bits Per Pixel	32 (forest height) 32 (quality)
Number of layers	2
Coverage on map	1° x 1°
Resolution on map [m]	200
Pixel spacing on map	
50° S - 50° N	3” x 3”
50° S - 60° S 50° N - 60° N	3” x 4.5”
60° S - 70° S 60° N - 70° N	3” x 6”
Temporal coverage	Inherited from processed L2a within global cycle
Product accuracy	Root mean square error < 30%
Data Size	
Approx. # of Latitude Samples	1201
Approx. # of Longitude Samples	
50° S - 50° N	1201
50° S - 60° S 50° N - 60° N	801
60° S - 70° S 60° N - 70° N	601
Max Data Volume [MB]	(full tile coverage)
50° S - 50° N	11
50° S - 60° S 50° N - 60° N	7
60° S - 70° S 60° N - 70° N	6

Max Data Volume (Final Format) [MB]	(full tile coverage)
50° S - 50° N	7
50° S - 60° S 50° N - 60° N	5
60° S - 70° S 60° N - 70° N	3

Tab.16 L2b/L3 Forest Height product definition table.

Notes:

- for the computation of data sizes indicative numbers from [AD15] subject to review;
- pixel spacing values have been computed considering nearly half the resolution values in both directions, to take into account effects of detection operation on data spectrum;
- volumes are indicated in two "versions": referred to binary data only and considering no compression applied to GeoTIFF files (32 bits for float, 8 bits for integer components); referred to the complete L2b FH product included BPS_FNF and Heat Map [AD10] and consisting in compressed GeoTIFF files for binary data. For all the details on L2b FH product format and applied compression strategies refer to [AD10][AD1].
- GeoTIFF format is recommended over NetCDF.

4.2.4. Forest AGB

Product ID	**AGB_L2b/AGB_L3**
Product Type	L2b: Tile based, Geocoded, Multi-stack, Real L3: Tile based, Geocoded, Multi-stack, Real
Main Product Characteristics	
Pixel Value	AGB, quality
Coordinate System	DGG
Bits Per Pixel	32 (AGB) 32 (quality)
Number of layers	2
Coverage on map	1° x 1°
Resolution on map [m]	200
Pixel spacing on map	
50° S - 50° N	3” x 3”
50° S - 60° S 50° N - 60° N	3” x 4.5”
60° S - 70° S 60° N - 70° N	3” x 6”
Temporal coverage	Inherited from processed L2a within global cycle
Product accuracy	Bias smaller than 30 Mg/ha RMS AGB error < 50% or less for biomass < 200Mg/ha RMS AGB error < 30% or less for biomass > 200Mg/ha
Data Size	
Approx. # of Latitude Samples	1201
Approx. # of Longitude Samples	
50° S - 50° N	1201
50° S - 60° S 50° N - 60° N	801
60° S - 70° S 60° N - 70° N	601
Max Data Volume [MB]	(full tile coverage)
50° S - 50° N	11
50° S - 60° S 50° N - 60° N	7
60° S - 70° S 60° N - 70° N	6
Max Data Volume (Final Format) [MB]	(full tile coverage)
50° S - 50° N	7
50° S - 60° S 50° N - 60° N	5
60° S - 70° S 60° N - 70° N	3

Tab.17 L2b/L3 Forest AGB product definition table.

Notes:

- for the computation of data sizes indicative numbers from [AD15] subject to review;
- pixel spacing values have been computed considering nearly half the resolution values in both directions, to take into account effects of detection operation on data spectrum;
- volumes are indicated in two “versions”: referred to binary data only and considering no compression applied to GeoTIFF files (32 bits for float, 8 bits for integer components); referred to the complete L2b AGB product included BPS_FNF and Heat Map [AD11] and consisting in compressed GeoTIFF files for binary data. For all the details on L2b AGB product format and applied compression strategies refer to [AD11][AD1].
- the final product is subject to review in Y3;
- GeoTIFF format is recommended over NetCDF.

5. Appendix A: Product Description Terminology

5.1. L1 product description terminology

Coordinate System
Products can be represented in the slant range coordinate system (SCS products) or in the ground range coordinate system (DGM products). The slant range and ground range represented products are produced in Zero-Doppler orientation, i.e. with each row of pixels representing points along a line perpendicular to the sub-satellite track.

Bits per Pixel
A pixel can be represented by either a pair of floats (representing the amplitude and phase parts of a complex number) or a single float (representing just the amplitude part) or an unsigned integer (for the binary images). Therefore, the number of bits per pixel is:

- 64 for complex products;
- 32 for detected products.
- 8 for binary products.

Ground Range Coverage
The ground range coverage is the nominal range (across-track) dimension of the area on the ground surface represented in the image. The azimuth (or along-track) dimension of the image can be of any length and potentially as long as the acquisition segment. For some calculations in the product definition, however, the nominal length of each product has been defined to be equal to the ground range coverage.

Resolution
The spatial resolution of an imaging system is a measure of its ability to distinguish between adjacent targets. The spatial resolution is defined as the Impulse Response Function width (IRW) measured at 3 dB (half of the intensity) below the peak value, in either range or azimuth direction.
The Impulse Response Function (IRF) (or the point target response) of a SAR system (sensor and processor) is the 2-D image of a point target in either slant range or ground range representation, neglecting effects of background clutter and thermal noise.
The intensity of the IRF is significant mainly along the range and azimuth directions and therefore, 1-D slices in range and azimuth, are used to characterize the 2-D IRF.

Pixel Spacing
Pixel spacing is the distance between adjacent pixels in an image measured in meters. This is the same as the pixel size. The pixel spacing may be different for range and azimuth.

Range pixel spacing may be stated in slant range distance for SCS products or in ground range distance for DGM products.

Typically, for complex-valued images, the pixel spacing in each dimension of the image is similar in magnitude to the resolution in that dimension. For detected images, the pixel spacing in each dimension is similar in magnitude to half the resolution in that dimension. In order for the full information content of the image to be retained, the pixel spacing must meet the Nyquist criterion. To meet this criterion, the spatial sampling rate must exceed the bandwidth of the spatial frequency content in the image.

Incidence Angle

The incidence angle is the angle between the incident SAR beam and the axis perpendicular to the local geodetic ground surface. The values provided in Sec. 4 are nominal in that they are calculated assuming that the local surface follows the ellipsoid, without any adjustment for the terrain height.

For BIOMASS, the off-nadir angles, and implicitly the incidence angles, vary with position of the satellite in orbit due to the roll steering law. The incidence angle values specified in each product table represent, for each beam, the approximate incidence angle at mid swath and averaged over the orbit.

Equivalent Number of (Independent) Looks (ENL)

The image speckle statistics for areas of distributed target are determined by the multi-looking used in image generation. The equivalent number of independent looks (ENL) for a given product type is intended to correspond to the number of equally weighted, statistically independent looks which would produce the same speckle statistics as the processing used to generate the product.

For a distributed target (large enough to ensure statistical accuracy) in a perfectly homogeneous area of a SAR image generated using NL equal, independent looks:

$$N_L = \frac{\mu^2}{\sigma^2} \tag{5.1}$$

where μ and σ are respectively the mean and the standard deviation of signal power over the distributed target. This ratio is therefore used to define the equivalent number of independent looks for the general case (non-independent looks):

$$ENL = \frac{\mu^2}{\sigma^2} \tag{5.2}$$

The ENL will normally be less than the total number of looks, NL, because of partial overlapping of the looks and unequal weighting.

Radiometric Resolution

The radiometric resolution is a measure of the ability to distinguish between uniform distributed targets with different backscattering coefficient. It is measured on a homogeneous distributed target, large enough to ensure statistical accuracy:

$$RR = 10\log_{10}\left(1 + \frac{1}{\sqrt{ENL}}\right) \tag{5.3}$$

Peak Side Lobe Ratio (PSLR)

The peak side lobe ratio is the worst-case measure of the SAR ability to identify a weak target from a nearby strong target. The PSLR is defined as the ratio of the peak intensity in the main-lobe of the IRF to the peak intensity of the most intense side- lobe over 10 times the 3dB-IRW in each azimuth and range direction.

Integrated Side Lobe Ratio (ISLR)

The ISLR characterizes the SAR ability to detect weak targets in the neighborhood of strong targets. The ISLR is defined as the ratio of energy within the main lobe of the IRF (defined as lying within a rectangle of size 2x and 2y centered on the peak, where x and y are the 3dB widths in range and azimuth) and the energy outside of this area integrated over a region bounded by sides 10 times longer.

2D Distributed Target Ambiguity Ratio (2D-DTAR)

The unambiguous zone in defined, in the range direction by the nominal swath width and in the azimuth direction by the total processed Doppler bandwidth. An ambiguous zone is defined as a region outside the unambiguous zone.

The 2D Distributed Target Ambiguity Ratio (2D-DTAR) is the ratio of energy contribution from a distributed target in the unambiguous zone to the energy contribution from a distributed target located in the unambiguous zone.

The ratio is to be calculated using the Distributed Target Radar Cross Section Reference Model $\mathrm{P'T}/\Sigma\mathrm{PA}$, where: $\mathrm{P'T}$ is the intensity of the radar response to a distributed target located within the unambiguous zone, and $\Sigma\mathrm{PA}$ is the summed intensity of the radar responses to the respective distributed targets within the various ambiguous zones.

Point Target Ambiguity Ratio (PTAR)

The Point Target Ambiguity Ratio is specified as the ratio PT/PA, where:

- PT is the peak intensity of the radar response to a point target located within unambiguous zone;
- PA is the peak intensity of the radar response to a point target of the same radar cross-section as defined for PT but located within the worst ambiguous zone. The PTAR can be defined in both the range and azimuth directions.

Noise Equivalent Sigma Zero (NESZ)

The Noise Equivalent Sigma Zero (NESZ) is a measure of the sensitivity of the radar to areas of low backscatter. The NESZ is defined as the backscatter coefficient.

σ_0 (back-scattering cross section of a distributed target per unit area) of a distributed target within the product coverage for which the signal power level in the final image is equal to the noise power level (thermal noise only), i.e., an image SNR of 0 dB.

Channel Co-registration Accuracy

The channel co-registration accuracy is a characteristic of the polarization products and it represents the difference between the location of the same point target in the different images, in either range or azimuth.

Radiometric Bias

The radiometric bias is defined as the residual offset of the normalized radar cross-section measurements. It includes errors from processing and calibration.

Radiometric Stability

The radiometric stability is defined as p-times (with p = 1, 2 or 3) the standard deviation of the normalized radar cross-section measurements of a well characterized reference target (such as transponders, corner reflectors and distributed targets), taken at different locations and times, over all spatial scales, excluding thermal noise, scene background noise, speckle effects and all Instrument related noises (e.g., distortion noise, ambiguity noise, bit error noise, quantization noise). The variability of the reference target shall be included in the radiometric stability budget, whereas perturbations due to propagation path of the electromagnetic signal shall be neglected. The radiometric stability is defined with the system operating within its dynamic range.

Absolute Location Accuracy

The pixel location accuracy is specified as the 3σ deviation in the estimate of the position of a point target of sufficiently large cross-section, the estimate being the point equidistant between the -3dB points of its detected impulse response measured in along-track and across-track directions. If the pixel location error depends on location within the image, the worst-case location is applicable. The values in the table assume that the Earth's surface follows the shape of the ellipsoid at a local specified elevation height. The use of ground truth data is not included.

Number of Range Looks

The number of range looks is the number of distinct or overlapping coherently processed looks extracted from the pulse bandwidth which are combined after detection to form the image.

Number of Azimuth Looks

The number of azimuth looks is the number of distinct or overlapping coherently processed looks extracted from the Doppler spectrum which are combined after detection to form the image.

Look Overlap

The look overlap is specified as the ratio between the size of the overlap between any 2 nearby looks and the size of the look.

Range Look Bandwidth

The range look bandwidth is the bandwidth of the segment of the total pulse bandwidth which is coherently processed for each individual range look.

Azimuth Look Bandwidth

For Stripmap type modes, the azimuth look bandwidth is the processed Doppler bandwidth for each individual azimuth look.

Hamming Window Coefficient

In the SAR processor, both the range and azimuth spectrum of the data are weighted by a (generalized) Hamming window defined by the (beam-dependent) coefficient specified for each product table. The Hamming window is defined by:

$$W(\alpha) = a - (1 - a) \cdot \cos(\alpha) \tag{5.4}$$

where the Hamming coefficient $\alpha \in [0,2\pi]$.

The weighting has opposite effects on resolution and side lobes level therefore the coefficient is chosen in such a way as to realize the desired trade-off between these IPF characteristics.

Range and Azimuth Resolution

The following formula has been used in order to compute the slant-range resolution:

$$\rho_{srg} = 0.886 \cdot \frac{c_0}{2 \cdot BW} \cdot IRW_{BF} \tag{5.5}$$

where IRW_{BF} is the broadening factor as described in the previous section, BW is the chirp bandwidth, and c_0 is the speed of light.

The following formula has been used in order to compute the azimuth resolution:

$$\rho_{az} = 0.886 \cdot \frac{v_g}{BW_{az}} \cdot IRW_{BF} \tag{5.6}$$

where IRW_{BF} is the broadening factor as described in the previous section, BW_{az} is the azimuth processed bandwidth, and v_g is the ground velocity, which is slightly latitude and range dependent.

5.2. L2/3 product description terminology

Number of layers

L2/3 FH and AGB products are generated with a quality layer indicating the estimation quality based on an error model for each pixel. Error model is based on a noise and statistical computation budget and interferometric sensitivity (baseline). L2 FD product is generated with a layer representing deforestation, a layer representing the forest/non-forest mask updated with current global cycle changes and a probability of change, being the FD quality layer. L2a GN is generated with 3 layers, accounting for each polarimetric channel.

Temporal coverage

L2/3 products are tagged with the start and stop dates corresponding to the L1c stack interval used to generate them.

Coordinate System

Products are represented in DGG relying on latitude-longitude (WGS84). Data dimensions are latitude-longitude in degrees.

Coverage on map

The coverage of the geocoded product onto geographic grid.

6. Appendix B: Round-orbit Main Parameters Variation

In this section are collected the plots showing how the main parameters used to describe BIOMASS products in Sec. 4 vary round-orbit.
For this purpose, the following inputs have been used:

- BIOMASS Instrument RDB [AD2], in particular:
    - Generic SAR Timeline (GSTL-large) tables for SWP, SWL, PRI and RANK values;
    - Tx Pulse Lengths (TXPL) tables for transmitted pulse parameters;
- Example Orbit Files for BIOMASS INT and TOM Phases [AD3], in particular:
    - BIO_INT_AUX_ORBRES_20170101T060001_20170104T105401_0001.EOF file for INT phase;
    - BIO_TOM_AUX_ORBRES_20170101T060001_20170104T105401_0001.EOF file for TOM phase;
    - for each file, the first complete orbit has been used for the computations.

The following figures show the swath coverage, the swath overlap and the incidence angles for the 3 BIOMASS beams (S1, S2 and S3) and the total swath width versus latitude, respectively for the INT and TOM phases. Swath width is intended on ground and it has been computed considering the area at full resolution after focusing (i.e., removing transmitted pulse length from SWL quantity). Dependencies on latitude are clearly visible and are due to the fact that several parameters vary along orbit, in particular the satellite altitude and the instrument acquisition parameters (PRF, SWP, SWL, transmitted pulse length). While the greatest part of these parameters changes smoothly, PRF changes are responsible of the sudden “jumps” visible in particular in the swath overlap plots.

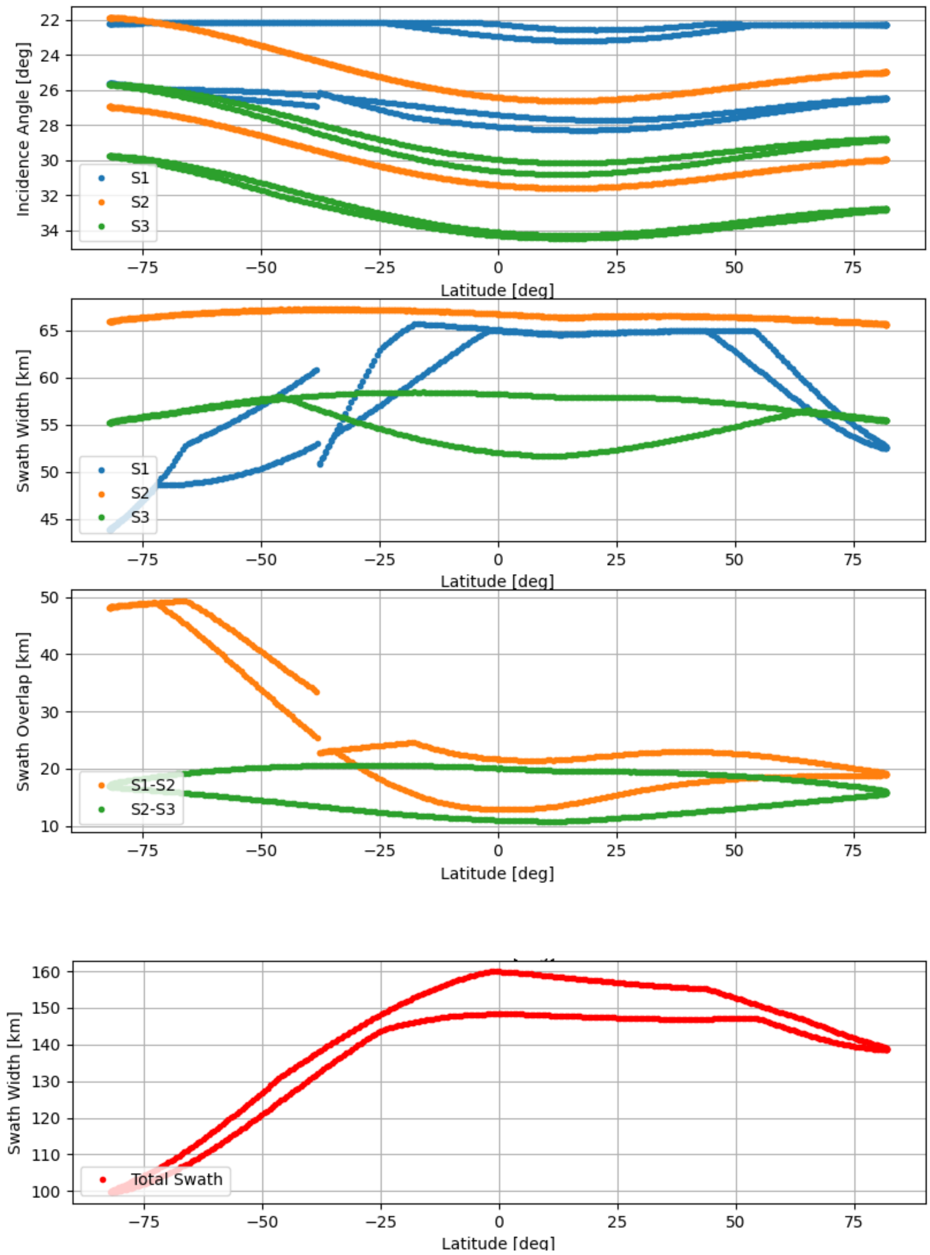


Fig.9

INT phase: swath width (1), swath overlap (2) and incidence angle (3) versus latitude for the 3 BIOMASS beams (S1, S2 and S3) and total swath width (4) versus latitude.

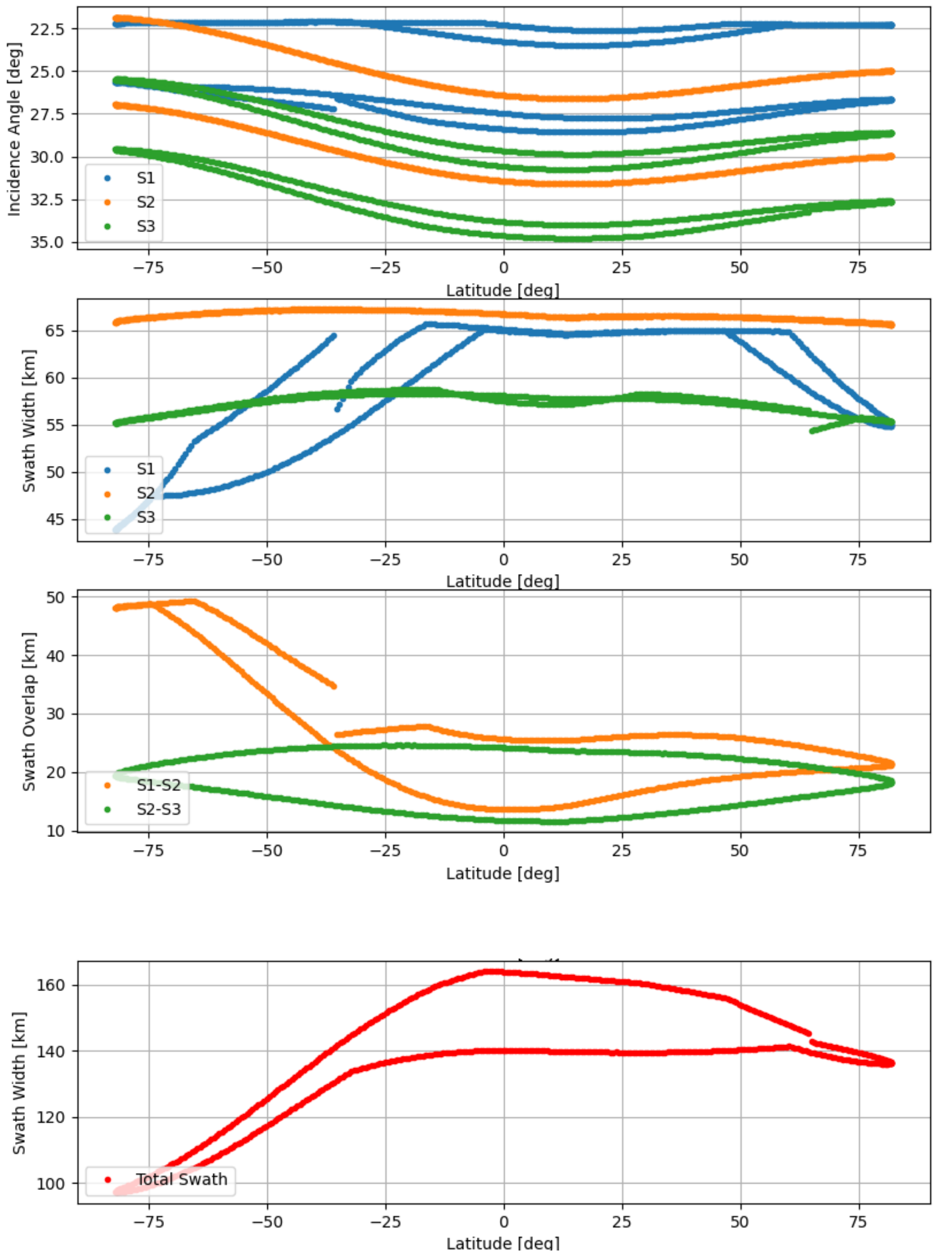


Fig.10

TOM phase: swath width (1), swath overlap (2) and incidence angle (3) versus latitude for the 3 BIOMASS beams (S1, S2 and S3) and total swath width (4) versus latitude.

For the sake of completeness, values have been computed also considering a delta-terrain height of 5000m. While the impact on incidence angle is ~1/1.5deg, the impact on swath width and swath overlap is almost negligible, as expected.