CCI

BIOMASS

SYSTEM REQUIREMENTS DOCUMENT

YEAR 1

VERSION 1.0

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SYMBOLS AND ACRONYMS

AGB	Above Ground Biomass
ALOS	Advanced Land Observing Satellite
ATBD	Algorithm Theoretical Basis Document
AWS	Amazon Web Services
BCEF	Biomass Conversion & Expansion Factor
CCI	Climate Change Initiative
CCI-Biomass	Climate Change Initiative – Biomass
DARD	Data Access Requirements Document
DEM	Digital Elevation Model
DSWG	Data Standards Working Group
ECV	Essential Climate Variables
EO	Earth Observation
ESA	European Space Agency
FBD	Fine Beam Dual
GRD	Ground Range Detected
GSV	Growing Stock Volume
ICESAT GLAS	Ice, Cloud, and land Elevation Satellite Geoscience Laser Altimeter System
IWS	Interferometric Wide Swath
JAXA	Japan Aerospace Exploration Agency
PALSAR	Phased Array type L-band Synthetic Aperture Radar
PS	Processing System
PSD	Product Specification Document
PVASR	Product Validation and Algorithm Selection Report
PVP	Product Validation Plan
S1, S2	Sentinel-1, Sentinel-2
SAR	Synthetic Aperture Radar
SOW	Statement Of Work
SRD	System Requirements Document
TBC	To Be Confirmed
TBD	To Be Decided
URD	User Requirements Document

1. Introduction

The European Space Agency (ESA) Climate Change Initiative (CCI) aims to generate high quality Essential Climate Variables (ECVs) derived from long-term satellite data records to meet the needs of climate research and monitoring activities, including the detection of variability and trends, climate modelling, and aspects of hydrology and meteorology.

1.1. Purpose

The aim of this document is to collect all requirements on the CCI+ Biomass Processing System (PS). Main sources are the reference documents listed in Table 1 especially the SOW with its Annex and the first project deliverables (in particular the User Requirements Document; URD and Product Specification Document; PSD), and the CCI project guidelines.

The processing algorithms and output products are being defined to some degree in parallel to this document. This affects some key areas such as the system performance and sizing. Therefore, this document will be updated continuously but it is also kept generic to be independent from the details of the algorithms to be implemented. When appropriate and necessary TBC (To Be Confirmed) and TBD (To Be Defined) has been used.

The requirements have a unique 3 level identifier SW-TYPE-ID. The BM stands for CCI+ Biomass. The type is defined similarly to other CCI System Requirements Documents (SRD):

FUN: functional

PER: performance

SIZ: sizing

INT: interface

OPE: operational

RAM: availability, maintainability, security

The ID is a 4-digit number.

1.2. Scope

The scope of the SRD is defined in the SoW [R-1]: “Create a System Requirements Document (SRD) specifying the requirements of a Processing System capable of generating ECV data products as specified in the applicable technical annex (A-I). The SRD shall include verifiable requirements on the following: Data processing function of each step of its processing chain, including data volumes; Platform specification; Compliance to all processing needs defined by the Task 3 inputs.”

1.3. Document Structure

In Section 2 the *Biomass_cci* processing system is presented by giving an overview of the system. In Section 3 different scenarios are discussed. Section 4 describes the workflow of the processing system for both products, the snow cover fraction and the snow water equivalent. The detailed requirements are finally listed in Section 5.

1.4. Document Status

This document is based on issue 1.1 of the Data Access Requirements Document (DARD), Issue 1.1 of the PSD, and Issue 1.0 of the URD; refinement of this document will be necessary depending on future issues of these documents.

1.5. Reference Documents

Table 1 below lists the reference documents of the system requirements.

Table 1: Reference Documents

Acronym	*Title*	*Issue*
R-1	CCI+ SoW Issue 1.4 r2	EOP-SEP/SOW/0031-1.4 r2
R-2	User Requirements Document (URD)	1.0
R-3	Product Specification Document (PSD)	1.1
R-4	Data Access Requirements Document (DARD)	1.1
R-5	Data Standards Guidelines (DSWG)	
R-6	Algorithm Theoretical Basis Document (ATBD)	
R-7	Product Validation and Algorithm Selection (PVASR)	
R-8	Product Validation Plan (PVP)	

2. CCI+ Biomass Processing System Overview

2.1. Context

The CCI+ Biomass PS has to consider the following issues for each of the products:

- Data archive
- Data production

- Data services

Data archiving relates to the need to retrieve and store the input data, auxiliary products (e.g. DEMs), intermediate products from the applied algorithms, and output data (final products).

The data production deals with the generation of the final products, including meta-data and log files.

The data services issue is related to data accessibility of the final products for the scientific community. For the first issue it has to be considered that for all products mandated repositories exist so that the PS only has to consider the datasets that are required for data production.

Selected common services may be offered within the CCI projects for sharing among ECVs. Among them are a backup archives for the data, cloud services that can be used by other ECVs, and a CCI product viewer.

The common data access layer shared among all ECVs provides harmonised access to CCI data for climate modellers. This shall lower the barrier for climate users to use several of the ECVs. The individual production and data environments per ECV are close to the scientific groups to support an agile, continuous development and nimble reaction to issues with short cycles. The production environments are optimised for re-processing and validation. Strict versioning ensures production of stable product releases. Optionally, sharing of an environment by production and development also allows access to long time series for the scientific improvement cycle.

2.2. User Requirements

The User Requirements are documented in the User Requirements Document [R-2].

3. CCI+ Biomass Processing System Scenarios

3.1. Sensor Constellation and Temporal Coverage

The sensor constellation and temporal coverage is described in detail in R-4, the corresponding DARD document. An overview of EO data to be used for the global map production is provided in Table 2. Figure 4 and 5 show the number of observations globally.

Table 2: Overview of EO data used for the global map production

PRODUCT		SOURCE	ACCESS	COVERAGE		VOLUME (Tb)	COMMENTS
SATELLITE	SENSOR			SPATIAL	TEMP	INPUT	
Sentinel -1A/B	IWS	ESA Google Earth Engine[1]	Open	Glob	2014 & 2017 - 2018	100 yr^{-1}	Available at Gamma *Processed data

ALOS-2	PALSAR- 2	JAXA	Open	Glob(25 m)	2015-2016	TBD	Available at Gamma and Aberystwyth U.

3.2. Products and Variables

The CCI+ Biomass products consists of global maps of the aboveground biomass for the epochs 2017-2018, 2018-2019 and 2010. It has been agreed within the CCI+ Biomass consortium that the data products will be delivered at 100 m resolution. Each map is accompanied by a map describing the pixel level standard error of the estimated AGB. The product formats are described in detail in R-3 (Product Specification Document).

3.3. Reprocessing Capability

It is an important requirement of the processing system that Earth Observation (EO) data can be reprocessed. Consequently, the process must be reproducible and the system sufficiently powerful to allow reprocessing in time. Reprocessing can be due to improved input data quality, improved processing software or improved algorithms.

An important feature is the possibility of only running parts of the system. This allows intermediate results to be kept and reduces the reprocessing resources and time.

3.4. Improvement Cycle

Another common topic identified in the Systems Engineer Working Group is the versioning and improvement cycle. A favourite approach by the CCI system engineers is suggested by the Science Leader of the Sea Surface Temperature CCI (SST_cci) project C. Merchant and shown in Figure 1.

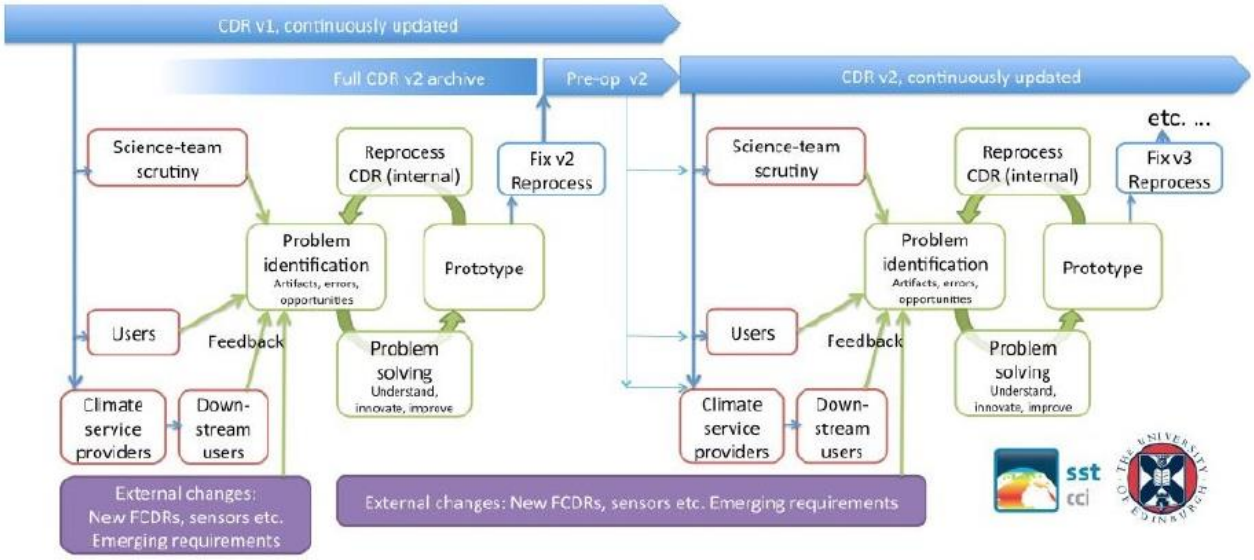

Figure 1: Processing system module improvement and product versioning (by C. Merchant for SST_cci).

3.5. Interaction with Users

There is no foreseen direct interaction between the PS and the users. Communication with the users is done through the project management. Data access for the users is enabled through the dedicated cci product portals.

4. CCI+ Biomass Processing System Production Workflow

The production workflow consists of different modules (Figure 2):

- preprocessing
- retrieval
- product generation
- verification/validation

In the following we describe the modules implemented to obtain the data product foreseen for year 1, i.e., a global map of above-ground biomass (AGB) for the epoch 2017-2018.

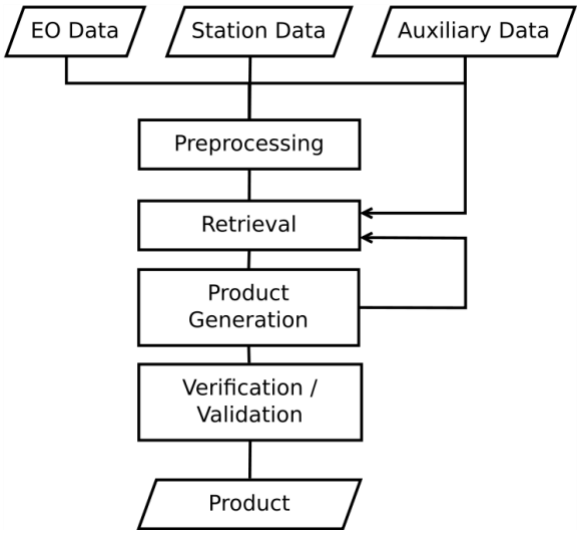

Figure 2: CCI+ Biomass Processing System Production Workflow

4.1. Preprocessing

The following EO datasets were processed during year 1 of the CCI Biomass project but are not considered to be part of the system developed for CCI Biomass:

- Sentinel-1
- ALOS-2

The data in ready-to-use format are to be considered input to the biomass retrieval part described in the next Section. Accordingly, all datasets to be used in support of the model training part and/or the retrieval part are resampled and tiled to the same pixel spacing and the geometry.

The radar data pre-processing covers all steps from Synthetic Aperture Radar (SAR) data intake to orthorectified calibrated backscatter images. This includes preparation of auxiliary data needed for the processing, sampling to a common reference grid etc.

Processing of the Sentinel-1 (S1) data is implemented to obtain calibrated backscatter images with sub-pixel co-registration accuracy, arranged in a structure that allows for easy access and management. To this end, a global grid tied to the geographic reference system and having its origin at 90° N, 180° W, with tiles of relatively small size is used. The Sentinel-1 images (with an original spatial resolution of approximately ~15 m) are geocoded to a pixel size of 1/720th of a degree in both latitude and longitude and tiled into 1°×1° tiles (i.e., 720 × 720 pixels). The commercial software package by GAMMA Remote Sensing was used for the pre-processing of the Sentinel-1 data. The flowchart of the S1 data pre-processing is shown in Figure 3. For details, it is referred to in R-6. All IWS (Interferometric Wide Swath) images in GRD (Ground range detected) format in the S1 archives for the year 2017 were considered. The large number of images (~250000 scenes globally) necessitated implementation of the S1 pre-processing on Amazon Web Services (AWS). The number of images available for 2017 are illustrated in Figure 4.

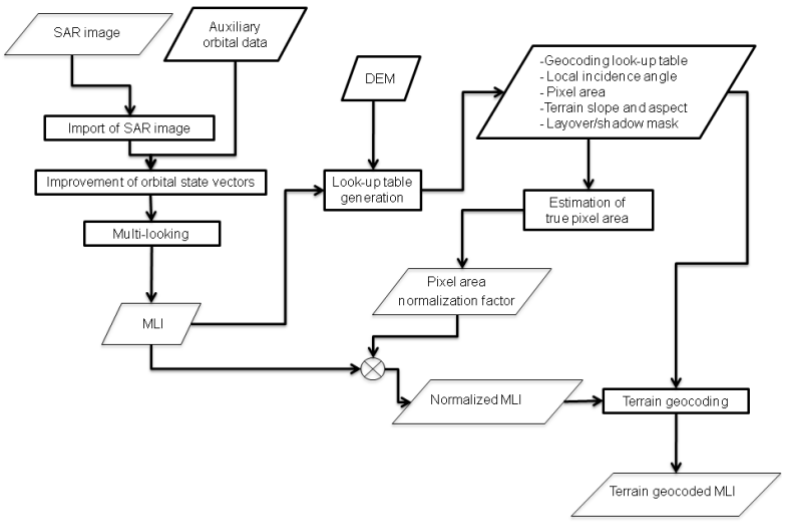

Figure 3: Flowchart of Sentinel-1 pre-processing.

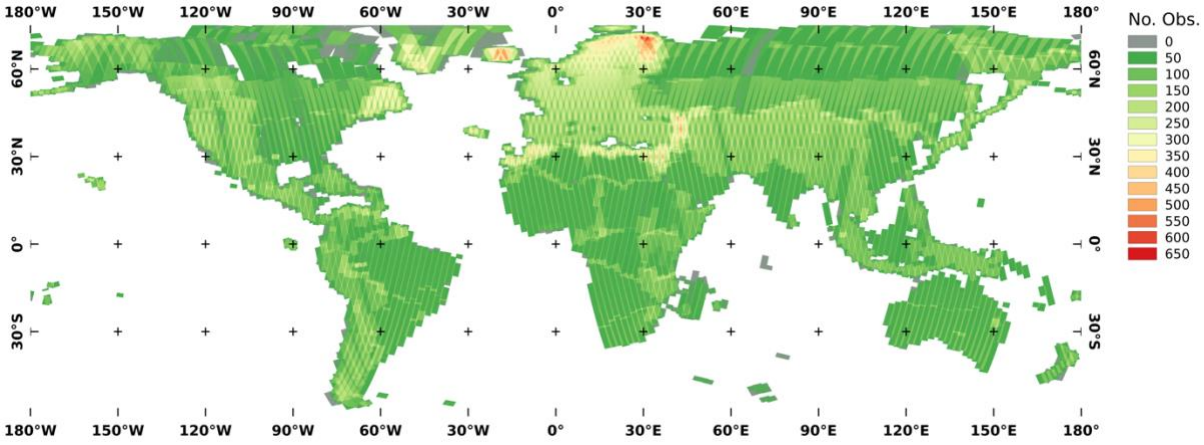

Figure 4: Number of observations per pixel for the Sentinel-1 dataset of 2017 processed to support the estimation of forest biomass for the epoch 2017-2018.

ALOS-2 datasets are available through the Japanese Aerospace Exploration Agency JAXA, which releases fully pre-processed (i.e., calibrated, geocoded, tiled) datasets in a ready-to-use format. Global mosaics of the L-band backscatter at two polarizations acquired in Fine Beam Dual-polarization mode (FBD) are released on an annual basis. So far, FBD mosaics with a spatial resolution of ~25 m x 25m for the years 2015 to 2017 have been released. In addition, per-observation-cycle mosaics of ALOS L-band backscatter acquired in two polarizations in ScanSAR mode have been released. Most of the per-cycle mosaics with a spatial resolution of ~50 m x 50 m cover the wet tropics. Up until now, available ScanSAR mosaics cover the time frame between 2016 and mid 2018. Figure 5 provides an overview of the number of L-band observations available when combining FBD and ScanSAR mosaics.

Post-processing of the ALOS-2 data comprised:

1) aggregation to the CCI Biomass target resolution of 1/1125° (i.e., 0.00088889° x 0.00088889°)

2) Co-registration with previously released global mosaics of the L-band backscatter from ALOS PALSAR (which served as input to the production of the GlobBiomass map).

For further details on the ALOS-2 post-processing, the reader is referred to R-6.

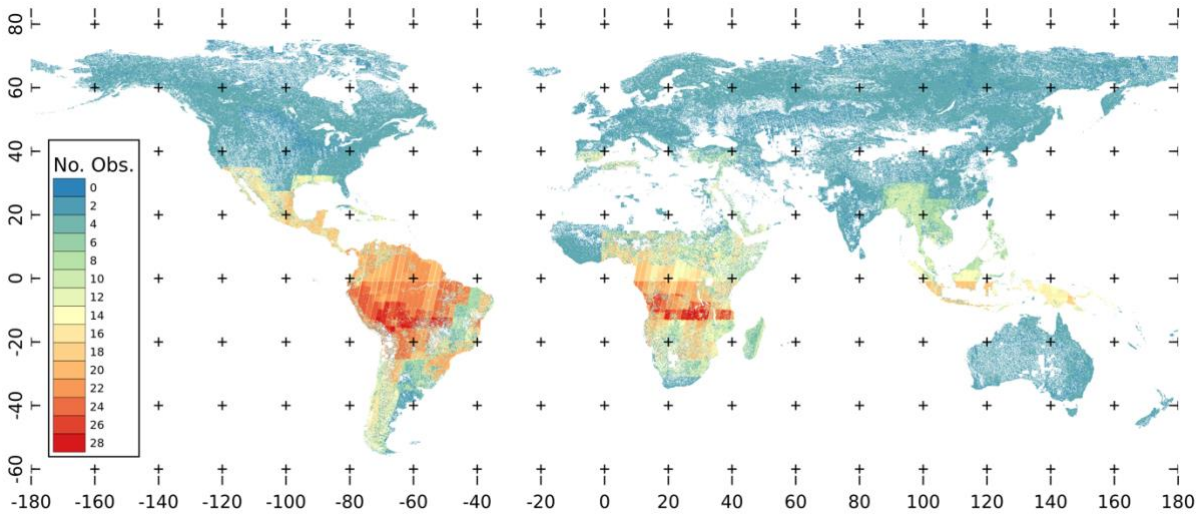

Figure 5: Number of ALOS-2 FBD and ScanSAR observations available for mapping GSV globally in the time frame 2015-2017.

4.2. Retrieval

In the retrieval module, the biomass and related uncertainties are estimated. In year 1 of the project, the structure of the biomass retrieval algorithm (Figure 6) follows the design of the retrieval algorithm that had been implemented for the production of the GlobBiomass map products for the year 2010, which is considered the CORE algorithm in CCI Biomass. In the following years of the project, biome specific solutions may be used to complement/improve the CORE. EO datasets and approaches with potential for large-scale mapping of biomass have been identified in R-7. Implementation, which has to comply with the system design for the baseline approach, and validation of these approaches was pending by the time of writing this document and is therefore not addressed below.

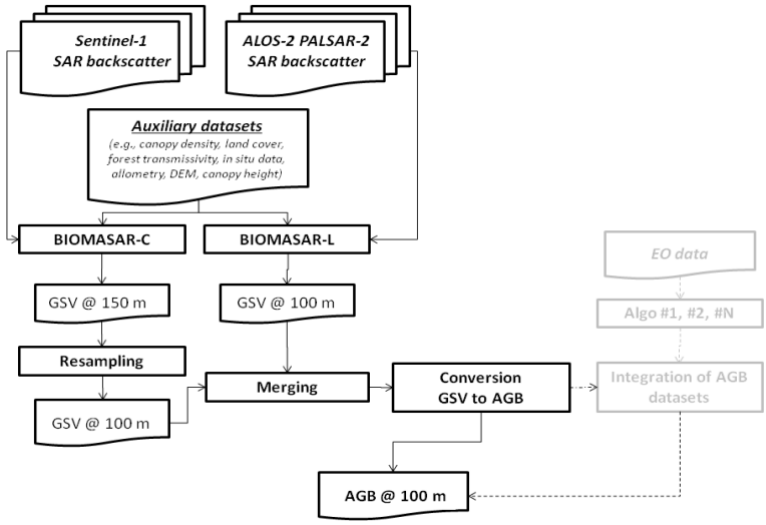

Figure 6: Flowchart of CCI Biomass global biomass retrieval algorithm.

To best exploit the global EO datasets currently available, the retrieval is arranged in a sequence of three stages (Figure 6).

With the first stage, a global dataset of Growing Stock Volume (GSV) is derived from the multi-temporal dataset of Sentinel-1 backscatter images with a pixel spacing of ~150x150 m^2 with the BIOMASAR-C algorithm (Santoro et al. 2011, Santoro et al. 2015). To avoid confusion with an implementation of BIOMASAR using L-band data in the next stage, we use the acronym BIOMASAR-C for stage 1.

This stage requires the stack of co-registered Sentinel-1 images described in Figure 6 and performs model training with the auxiliary datasets listed in Figure 6 followed by single-image and multi-temporal retrieval of forest GSV. The model training and single-image retrieval are spatially adaptive, implying a precise but yet time consuming approach since the settings for the estimation of the model parameters need to be adjusted at sub-degree scale. The BIOMASAR-C model calibration approach aims at capturing the spatial and temporal variability of the C-band SAR backscatter to biomass relationship. Running the training model on different regions in parallel is typically applied since the processing chain consists of a sequence of simple commands, thus not requiring substantial hardware configurations. The single-image retrieval generates estimates of forest GSV; it is straightforward and is applied sequentially on all images to all pixels for which a valid set of model parameter estimates have been obtained. The multi-temporal combination of single-image estimates of GSV is also straightforward since it is a mere linear combination of the GSV estimates weighted with a backscatter contrast metric derived from the estimates of two of the model parameters.

The second approach is based on the BIOMASAR-C model calibration and inversion approach, adapted for dual polarization backscatter from ALOS-2. It is therefore referred to as BIOMASAR-L. Modifications of the BIOMASAR retrieval approach were required regionally concerning the model calibration and inversion approach as well as the general implementation of the algorithm with the latter being required because the ALOS-2 data was provided by JAXA in the form of 1° x 1° tiles, each containing a mosaic of images acquired from several orbits. The modifications of the BIOMASAR algorithm for L-band are described in detail in the R-6 document. Model calibration for L-band is supported by estimates of forest height and canopy density, derived from ICESAT GLAS. Models are calibrated and inverted separately for each orbit contained in every 1° x 1° tile of the global ALOS PALSAR mosaics. The algorithm has been coded in the form of a sequence of bash and Matlab scripts, which perform 1)

the data preparation (e.g., multi-temporal filtering, generation of subsets), 2) model calibration, and 3) model inversion. The hardware requirements are low and parallelization is easy to realize given the tile-by-tile implementation of the algorithm.

The global GSV maps produced with BIOMASAR-C and BIOMASAR-L are accompanied by maps depicting the pixel-level uncertainty of the estimates in form of the standard error. Error models have been defined to characterize uncertainties associated with the backscatter measurements, the estimation of the model parameters for each image in the multi-temporal stack of observations, and the error associated with supporting datasets such as ICESAT GLAS. While straightforward to implement, the computation of uncertainties of multi-temporal estimates represents one of the most time-consuming steps in the retrieval sequence because retrieval errors of single-image GSV estimates tend to be correlated, necessitating the computation of covariance matrices. The calculation of covariance matrices is possible with sufficient computational efficiency when processing data on a tile-by-tile basis.

The GSV estimates from BIOMASAR-C and BIOMASAR-L are then merged to form the final GSV estimate. The rules have been described in R-6. The merging rules consider: i) differences in the sensitivity of C- and L-band to GSV in different GSV ranges, ii) local errors in the model parameter estimates, and iii) topographic effects, which tend to be more pronounced in the ALOS-2 derived maps because of the sub-optimal correction approaches used by JAXA when processing the backscatter mosaics.

Estimation of AGB from GSV is obtained by scaling with a biomass conversion and expansion factor (BCEF). The BCEF is the product of wood density and a factor representing the fraction of total biomass with respect to the stem biomass. Characterization of the BCEF therefore requires knowledge on both wood density and the allometric relationship between stem mass and whole above ground mass, including branches and leaves. In the GlobBiomass project, modelling of wood density and biomass expansion factors were pursued leading to generation of global wall-to-wall datasets based on extensive sets of measurements published in ecological databases. The same approach is used in CCI Biomass to obtain a global raster for the BCEF.

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4.3. Product Generation

The AGB maps and the maps of the AGB standard error are provided in an equiangular map projection with WGS-84 as datum. The pixel size in latitude and longitude is 0.00088888°, equivalent to approximately 100 m at the Equator. All data products are provided in Geotiff and netCDF formats.

4.4. Verification/Validation

Verification of the system is done by comparing with results obtained on local machines in a controlled environment with the same version of the software on the system. Data validation is done by project partners and external experts, further information can be found in the Product Validation Plan [R-8]. However, the CCI+ Biomass PS should perform consistency checks on the products before release to the experts.

5. Detailed CCI+ Biomass Processing System Requirements

The systems need to be designed to be sustainable. Hence there is a need to plan for evolution from the prototype approach towards compliance with applicable software standards e.g. appropriate components of ECSS- E-ST-40C. This implies the requirements for configuration control and maintenance (bug tracking, reprocessing, traceability), operability and transferability are priorities. They shall at the start of the project identify the correspondence between the documentation set within this project and those required by the applicable Software Standard.

Since the system is science-driven it must be capable of being regularly updated as scientific understanding improves and new algorithms are developed. The incorporation of new algorithms needs to consider trade-offs in cost, complexity and scientific impact on the quality and consistency of outputs, and the introduction of new algorithms must not jeopardise the output generation. The design should also be modular and flexible while at the same time capable of rapid reprocessing, thus the overall design needs to be developed with end-to-end throughput of the ECV production as a design priority.

Given the large amounts of data to be processed, the development is towards an automated high-performance processing chain. This processor shall be implemented on a sufficiently powerful (possibly distributed) computing infrastructure that is capable of processing and reprocessing all the required products within the project schedule.

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6.1. High Level System Requirements

BM-FUN-0010	Develop and validate algorithms to approach the GCOS ECV and meet the wider requirements of the Climate Community (i.e. long term, consistent, stable, uncertainty-characterized) global satellite data products from multi- sensor data archives. (CR-1)
BM-FUN-0020	Produce, validate and deliver consistent time series of multi-sensor global satellite ECV data products for climate science. (CR-2)
BM-FUN-0030	The CCI+ Biomass system shall generate the following product: Aboveground biomass maps @ 100 m resolution Maps @ 100 m resolution

	AGB difference maps for the three epochs considered in the project (spatial resolution to be defined).
BM-FUN-0040	Generate and fully document a production system capable of processing and reprocessing the data, with the aim of supporting transfer to operational activities outside CCI (such as C3S). [CR-4]
BM-OPE-0050	All project documentation shall be made publicly available via the CCI Open Data Portal: http://cci.esa.int.
BM-OPE-0060	The PS shall capitalise on existing European assets through their reuse, particularly Open Source scientific tools and prototype ECV processing systems from prior projects. (heritage)
BM-INT-0070	The global Biomass community shall play an active role in its creation according to given guidelines and advice from a strategic operations team. They shall also give feedback from the implementation to the strategic team.
BM-SIZ-0080	The system shall implement a data production line that is sufficiently flexible to continuously update and extend the database (e.g. with data from new sensors or better acquisitions).
BM-INT-0090	The available data shall be frequently reported and properly disseminated to the interested user communities.

6.2. Functional Requirements

BM-FUN-1020	The Products shall be uniquely identified.

BM-FUN-1030	The PS shall store data in a structured way using type, revision, date.
BM-FUN-1040	If input data is retrieved directly from a third party ground segment, the PS has to ensure that links are maintained and functionality is regularly checked.
BM_FUN-1050	The PS shall also be able to reprocess parts of the products.
BM-FUN-1060	The PS shall be able to do partial processing.

6.3. Performance Requirements

SW-SIZ-2010	The PS shall be able to do processing in due time.
BM-SIZ-2020	The PS shall be able to do reprocessing in due time.
BM-SIZ-2030	The PS shall be able to run on the available hardware infrastructure

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BM-SIZ-2020	The PS shall be able to do reprocessing in due time.
BM-SIZ-2030	The PS shall be able to run on the available hardware infrastructure

6.5. Interface Requirements

BM-INT-3020	The PS shall have the capability and interfaces to extend for future adaptations.

6.6. Operational Requirements

BM-OPE-4020	Development of the PS shall be under version control.
BM-OPE-4030	The system should be decoupled from the research
SW-OPE-4040	Development of the system shall be based on the user requirements, the selected algorithms and the developed standardized validation protocols.
BM-OPE-4050	The PS development shall be overseen by a science team that drives the development process.
BM-OPE-4060	Each PS installation includes a set of test tools, data and benchmark data to test PS integrity (end-to-end, interfaces)
BM-OPE-4070	If a module is based on a prototype, the prototype state has to be frozen until it is implemented.
BM-OPE-4080	The verification is regarded as successful, when all tests agree within TBD limits. Hashes are to be preferred where applicable.

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BM-OPE-4080	The verification is regarded as successful, when all tests agree within TBD limits. Hashes are to be preferred where applicable.

6.8. Reliability and Maintenance Requirements

BM-FUN-5020	The operational processor shall not overwrite existing data. Versioning shall be used instead.
BM-RAM-5030	The system developed shall be detailed as a separate self-standing document providing an overview of the system and its components, functionality of the system and its subsystems, inputs, outputs, resource key interfaces, and resource requirements.
BM-FUN-5040	Verification of the correct implementation of the prototype system against the algorithms developed is a fundamental part of the process.
BM-RAM-5050	The verification shall be documented in a Verification Report. It shall contain the chosen approach and the justification, the selected verification data set and the verification results.
BM-RAM-5060	The PS shall provide means against data loss of

	its input / output products.
BM-FUN-5070	All data stored in the system shall be available for the long-term (at least 15 years).