Copernicus Global Land Operations
”Vegetation and Energy”
“CGLOPS-1”
Service Contract N° 941115 – ISP - 2021

PRODUCT USER MANUAL

DRY MATTER PRODUCTIVITY (DMP)
GROSS DRY MATTER PRODUCTIVITY (GDMP)
NET PRIMARY PRODUCTION (NPP)
GROSS PRIMARY PRODUCTION (GPP)
COLLECTION 300M
VERSION 1.1

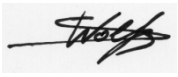
Issue I1.30

Organization name of lead contractor for this deliverable: VITO

Book Captain:	Davy Wolfs
Contributing Authors:	Else Swinnen
	Roel Van Hoolst
	Carolien Toté

Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document Release Sheet

Book captain:	Davy Wolfs		Sign  Date 16.06.2023	
Approval	Roselyne Lacaze		Sign Roselyne Lacaze Signature numérique de Roselyne Lacaze DN : cn=Roselyne Lacaze, o=HYGEOS, ou=Earth Observation Department, email=rl@hygeos.com, c=FR Date : 2023.06.30 15:51:10 +02'00' Date 30.06.2023	
Endorsement:	Michael Cherlet		Sign Date	
Distribution:	Public			

Change Record

Issue/Rev	Date	Page(s)	Description of Change	Release
	14.07.2020	All	Description of Collection 300m GDMP/DMP Version 1.1	I1.00
I1.00	10.09.2021	36-38	Summary of the validation results in Chapter 4	I1.10
I1.10	24.08.2022	All	Update after external review	I1.20
I1.20	16.06.2023	All	Update to include NPP and GPP	I1.30

TABLE OF CONTENTS

List of Figures

List of Tables

List of Acronyms

AD	Applicable Document
AFI	Area Fraction Image
AFRI	Africa
AR	Autotrophic Respiration
ATBD	Algorithm Theoretical Basis Document
CCI	Climate Change Initiative, an ESA program
CEOS	Committee on Earth Observation System
CF	Climate Forecast
CGLS	Copernicus Global Land Service
CNDVI	Cumulative NDVI
CSV	Comma Separated Values
DM	Dry Matter
DMP	Dry Matter Productivity
DN	Digital number
DTN	Data Transmission Network, United States private company
ε	Efficiency
EBF	Evergreen Broadleaf Forest
EC	European Commission or Eddy Covariance
ECMWF	European Centre for Medium-Range Weather Forecasts
ENVISAT	Environment satellite from ESA, contains MERIS instrument
ERA-Interim	A global atmospheric reanalysis dataset from ECMWF
ESA	European Space Agency
fAPAR	Fraction of absorbed photosynthetically active radiation
FLUXNET	A global network of micrometeorological flux measurement sites that measure the exchanges of carbon dioxide, water vapor, and energy between the biosphere and atmosphere
GAUL	Global Administrative Unit Layers
GBOV	Ground-Based Observations for Validation
GCOS	The Global Climate Observing System
GDMP	Gross Dry Matter Productivity
GLC	Global Land Cover
GPP	Gross Primary Production
Ha	Hectares
HRES	High Resolution atmospheric model of ECMWF
IGBP	International Geosphere Biosphere Program
ImagineS	Implementation of Multi-scale Agricultural Indicators Exploiting Sentinels
Jp	Joule PAR

Jap	Joule APAR
Jt	Joule total radiation
JRC	Joint Research Centre
LAI	Leaf Area Index
LPV	Land Product Validation group of CEOS
LUE	Light use efficiency
MARS	Monitoring Agricultural ResourceS
MARSOP	MARS-operations
MERIS	Medium Resolution Imaging Spectrometer
MODIS	Moderate Resolution Imaging Spectroradiometer
NDVI	Normalized Difference Vegetation Index
NEE	Net-Ecosystem exchange
NEP	Net Ecosystem production
NetCDF	Network Common Data Format
NGO	Non-Governmental Organization
NPP	Net Primary Production
NRT	Near Real Time
OLCI	Ocean and Land Colour Instrument
PAR	Photosynthetically active radiation
PROBA-V	Vegetation instrument on PROBA platform, Belgian mission
PUM	Product User Manual
QAR	Quality Assessment Report
QFLAG	Quality Flag
R	Radiation
RS	Remote Sensing
S3	Sentinel-3
SOAM	South America
SPOT	Système Pour l'Observation de la Terre
T	Temperature
UN-LCCS	United Nations Land Cover Classification System
VGT	VEGETATION sensor onboard SPOT4/5
VITO	Flemish Institute for Technological Research
WGS	World Geodetic System
XML	Extensible Markup Language
XSL	Extensible Style sheet Language

EXECUTIVE SUMMARY

The Copernicus Global Land Service (CGLS) is earmarked as a component of the Land Monitoring service to operate "*a multi-purpose service component*" that provides a series of bio-geophysical products on the status and evolution of land surface at global scale. Production and delivery of the parameters take place in a timely manner and are complemented by the constitution of long-term time series.

Since January 2013, the Copernicus Global Land Service is continuously providing Essential Variables like Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation absorbed by the vegetation (fAPAR), surface albedo, Land Surface Temperature, soil moisture, burnt areas, areas of water bodies, and additional vegetation indices, which are generated every hour, every day or every 10 days on a reliable and automatic basis from Earth Observation satellite data.

This document describes the global Dry Matter Productivity Collection 300m Version 1.1 product, representing the daily growth of standing biomass. From January 2014 to June 2020, the DMP Collection 300m Version 1.0 product was calculated from the Collection 300m FAPAR V1.0 derived from PROBA-V sensor data. From July 2020 onwards, the production in Version 1.1 is continuing using the FAPAR V1.1 derived from Sentinel-3/OLCI sensor data. The product is calculated globally and made available to the user in near-real time every 10 days. The product provides Gross Dry Matter Productivity (GDMP), Dry Matter Productivity (DMP), Net Primary Production (NPP) and Gross Primary Production (GPP) information distributed in 4 separate files. They are delivered with a maximum of 3 days lag in Near Real Time (NRT), followed by consolidations in the course of the next 6 dekads.

1 BACKGROUND OF THE DOCUMENT

1.1 SCOPE AND OBJECTIVES

The Product User Manual (PUM) is the primary document that gives an overview of the product characteristics, in terms of algorithm, technical characteristics, and main validation results. The key information is summarized in Table 1.

Table 1: Summary of key information

Input data	
The DMP, GDMP, NPP and GPP Collection 300m Version 1.1 product is derived from the CGLS Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) Collection 300m Version 1.1, and hence follows the delivery scheme of this dataset [CGLOPS1_PUM_FAPAR300m-V1.1].	See §2.2.2, p.16
Retrieval algorithm	
The DMP, GDMP, NPP and GPP product of the Global Land service is computed with a Monteith variant.	See §2.2, p.16
File naming	
c_gls_<PROD>[-<RTx>]_<YYYYMMDDhhmm>_<AREA>_<SENSOR>_V<VERSION>	See §3.1, p.27
File format and product content	
Separate multi-layer netCDF files are delivered for DMP, GDMP, NPP and GPP variables, containing (G)DMP, NPP or GPP and QFLAG; an xml file with INSPIRE2.1[1] compliant metadata	See §3.2 and §3.3, pp. 28-30
Projection and grid information	See §3.4.2, p.38
Regular lat/lon grid (plate carrée) with resolution 1/336°	
Spatial information	
Longitude [180°W – 180°E], Latitude [85°N – 65°S]	See §3.4.2, p.38
Temporal information	
Three products per month, dated day 10, day 20 and last day of each month, corresponding to the end date of the compositing period. The product is provided in the following consolidations: RT0 (at dekad D), RT1 (at dekad D+1), RT2 (at dekad D+2) and RT6 (at dekad D+6).	See §3.4.3, p.38
Data policies	

[1] https://inspire.ec.europa.eu/metadata/

Data access is free and open	See §3.5, p. 39
Data access	
More details on data access are available on http://land.copernicus.eu/global/access.	See §3.6, p. 40
Contact	
Accountable contact: copernicuslandproducts@jrc.ec.europa.eu	See §3.6, p. 40
Scientific and Technical contact: helpdeskticket@vgt.vito.be	

1.2 CONTENT OF THE DOCUMENT

This document is structured as follows:

- Chapter 2 presents a description of the algorithm
- Chapter 3 describes the technical characteristics of the product
- Chapter 4 summarizes the main results of the quality assessment exercise
- Chapter 5 gives examples of the product usage

The user requirements are recalled in Annex.

1.3 RELATED DOCUMENTS

1.3.1 Applicable document

AD1: Part 2: Technical specifications of Framework Service Contract – Operation of the bio-geophysical variables systematic monitoring of the Global Land Component of the Copernicus Land Service 'CGLOPS' JRC/2020/OP/3213, 17th December 2020.

Available at https://land.copernicus.eu/global/documents/applicable

1.3.2 Input

Document ID	Descriptor
CGLOPS1_ATBD_DMP-NPP300m-V1.1	Algorithm Theoretical Basis Document of the Dry Matter Productivity and Net Primary Production Collection 300m Version 1.1
CGLOPS1_ATBD_FAPAR300m-V1.1	Algorithm Theoretical Basis Document of the FAPAR Collection 300m Version 1.1
CGLOPS1_PUM_FAPAR300m-V1.1	Product User Manual of the FAPAR Collection 300m Version 1.1

CGLOPS1_QAR_DMP-NPP300m-V1.1	Quality Assessment Report of the Dry Matter Productivity and Net Primary Production Collection 300m Version 1.1

Available at https://land.copernicus.eu/global/documents/products

1.3.3 External reference

ImagineS_RP2.1_ATBD-FAPAR300m	Algorithm Theoretical Basis Document LAI, FAPAR and FCOVER 300m.

Available at https://land.copernicus.eu/global/documents/products

GCOS-107 (2006):	Systematic Observation Requirements for Satellite-based Products for Climate: Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC https://library.wmo.int/doc_num.php?explnum_id=3813
GCOS-154 (2011):	Systematic Observation Requirements for Satellite-based data products for Climate Supplemental details to the satellite-based component of the Implementation Plan for the Global Observing System for Climate in Support of the UNFCCC: 2011 update https://library.wmo.int/doc_num.php?explnum_id=3710
GCOS-200 (2016):	The Global Observing System for Climate: Implementation Needs https://library.wmo.int/doc_num.php?explnum_id=3417

2 ALGORITHM

2.1 INTRODUCTION

NPP, or Net Primary Production, is an indicator of the rate at which plants produce net useful chemical energy expressed in mass of carbon per unit area per day (gC/m²/day). Similarly, DMP, or Dry Matter Productivity, gives an indication of the dry matter biomass increase (growth rate) of the vegetation and is directly related to the NPP, but customized for agro-statistics and expressed in kilograms of dry matter (kg DM) per hectare per day.

DMP and NPP images, in this case derived from PROBA-V (from January 2014 to June 2020) and from Sentinel-3/OLCI (from July 2020 onwards) imagery combined with (modelled) meteorological data from the European Centre for Medium-Range Weather Forecasts (ECMWF), are made available at 300m resolution and are updated every 10 days.

Dry Matter Productivity (DMP) and Gross Dry Matter Productivity (GDMP), or similarly Net Primary Production (NPP) and Gross Primary Production (GPP), are two components expressing components of Primary Production of ecosystems related to the creation of new organic matter by vegetation. GDMP (GPP) is the total amount of dry matter (carbon) "fixed" by land plants per unit time through photosynthesis (atmospheric CO2 into organic compounds). A substantial fraction of GDMP (GPP) supports plant autotrophic respiration (Ra), with the remainder allocated to the Dry Matter Productivity (DMP) (or Net Primary Production, NPP) of plant structural biomass in stems, leaves, and fruit, and, to a much lesser extent, volatile organic compounds used in plant defence and signalling (Gough, et al., 2011). GDMP (GPP) and DMP (NPP) both represent the above-and belowground part of plants. To convert DMP (NPP) into the aboveground part a root to shoot ratio should be applied on the DMP (NPP) values.

The DMP and NPP products are distributed in 4 separate files, named DMP (Dry Matter Productivity), Gross Dry Matter Productivity (GDMP), Net Primary Production (NPP) and Gross Primary Production (GPP). These DMP and GDMP are in fact equivalent of, respectively, NPP and GPP. The only difference (expect for the naming) is that DMP/GDMP are expressed in kg Dry Matter per hectare per day (kg DM/ha/day) while GPP/NPP are typically expressed as gram of carbon per square meter per day (gC/m^2/day). The name and unit choice of DMP was originally designed to align with the terminology used in agricultural monitoring applications. When the DMP algorithm and product were adopted by the Copernicus Global Land Service, the name and unit where adopted. But, in fact, DMP could be better called Dry Matter Production (instead of Productivity). To convert the values and units of DMP to NPP or GDMP to GPP a simple conversion factor was applied:

First, kg DM/ha/day can be converted into g DM/m^2/day since:

1 kgDM/ha/day = 1000 gDM/ha/day = 0.1 gDM/m^2/day

For the conversion of Dry Matter (DM) into Carbon (C) the conversion factor defined by IPCC (2003) can be used which states that vegetation dry matter generally consists of 50% of carbon. So gC/gDM = 0.5. To summarize, NPP and GPP are calculated from DMP and GDMP as follows:

$$NPP\ [gC/m^2/day] = DMP\ [kgDM/ha/day] \times 0.5 \times 0.1$$

$$GPP\ [gC/m^2/day] = GDMP\ [kgDM/ha/day] \times 0.5 \times 0.1$$

Similar to the relation between NPP and DMP also the agronomic equivalent of the Gross Primary Productivity (GPP) can be defined as Gross Dry Matter Productivity (GDMP). Scaling from NPP to GDMP or oppositely is similar to the scaling described above. The main difference between the NPP/DMP and GPP/GDMP is conversion with the Carbon Use Efficiency (CUE).

$$NPP = GPP \times CUE \text{ or } DMP = GDMP \times CUE$$

2.2 RETRIEVAL METHODOLOGY

2.2.1 Background

A simplified Monteith (1972) approach, using remote sensing data to provide the fraction of absorbed PAR-radiation (fAPAR), was first implemented by Veroustraete (1994) and provided NPP estimates for European forests. The current version of the DMP (and associated products) is a modification of this original model, operating on meteorological data from ECMWF and the CGLS fAPAR.

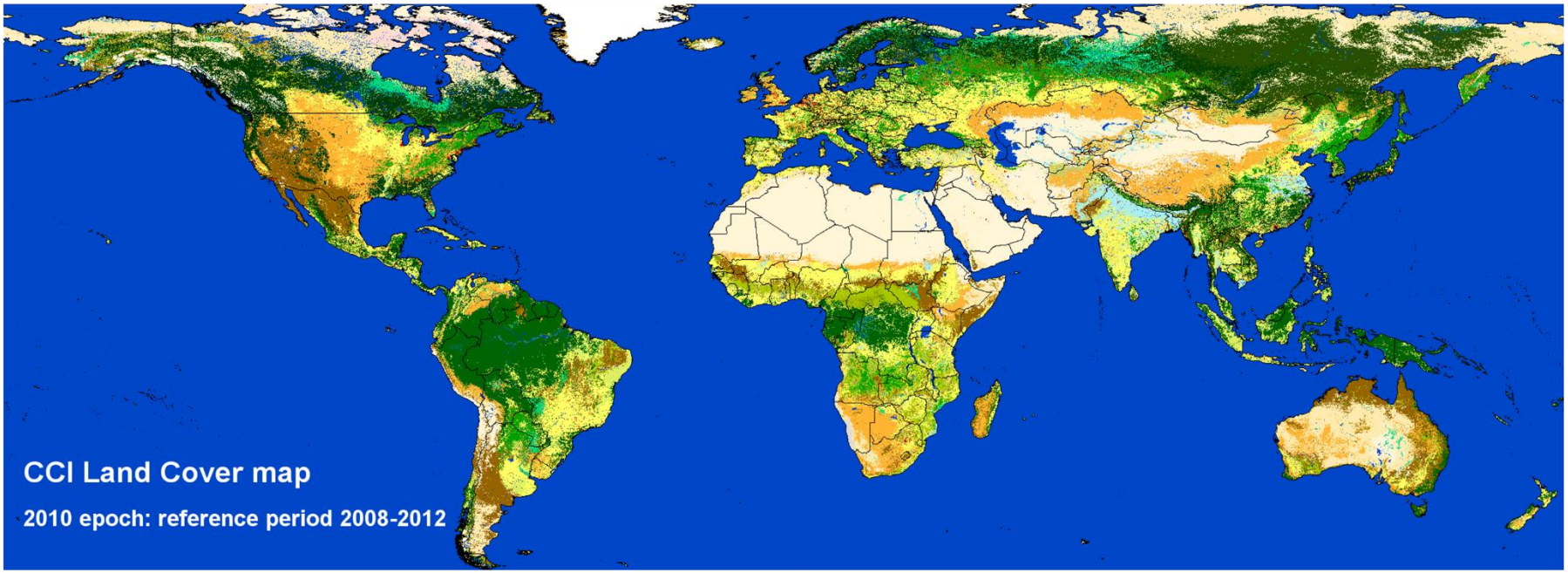
2.2.2 Input data

Meteorological data: Global meteorological data are retrieved from DTN, providing for each "grid-cell" (at 0.25° resolution) the values of all standard meteorological variables. Basically, all daily data are "operational forecasts for the next 24 hours" derived from ECMWF HRES model. Radiation, T_{min} and T_{max} are derived from this daily dataset for the DMP calculations.

fAPAR corresponds to the fraction of photosynthetically active radiation absorbed by the green elements of the canopy. It depends on canopy structure, vegetation element optical properties and illumination conditions. The 300 m DMP uses a 10-daily fAPAR based on PROBA-V data (from January 2014 to June 2020) [(ImagineS_RP2.1_ATBD-FAPAR300] and on Sentinel-3 data (from July 2020 onwards) [CGLOPS1_ATBD_FAPAR300m-V1.1].).

Land Cover information: The DMP 300m V1 uses biome specific Light Use Efficiency (LUE) values. The information on the global distribution of land cover types comes from the ESA CCI Land Cover Map (epoch 2010), which was derived from ENVISAT-MERIS and SPOT-VGT imagery of

the period 2008-2010. The land cover classes are based on the UN Land Cover Classification System (LCCS). The global map is shown in Figure 1.


CCI Land Cover map
2010 epoch: reference period 2008-2012

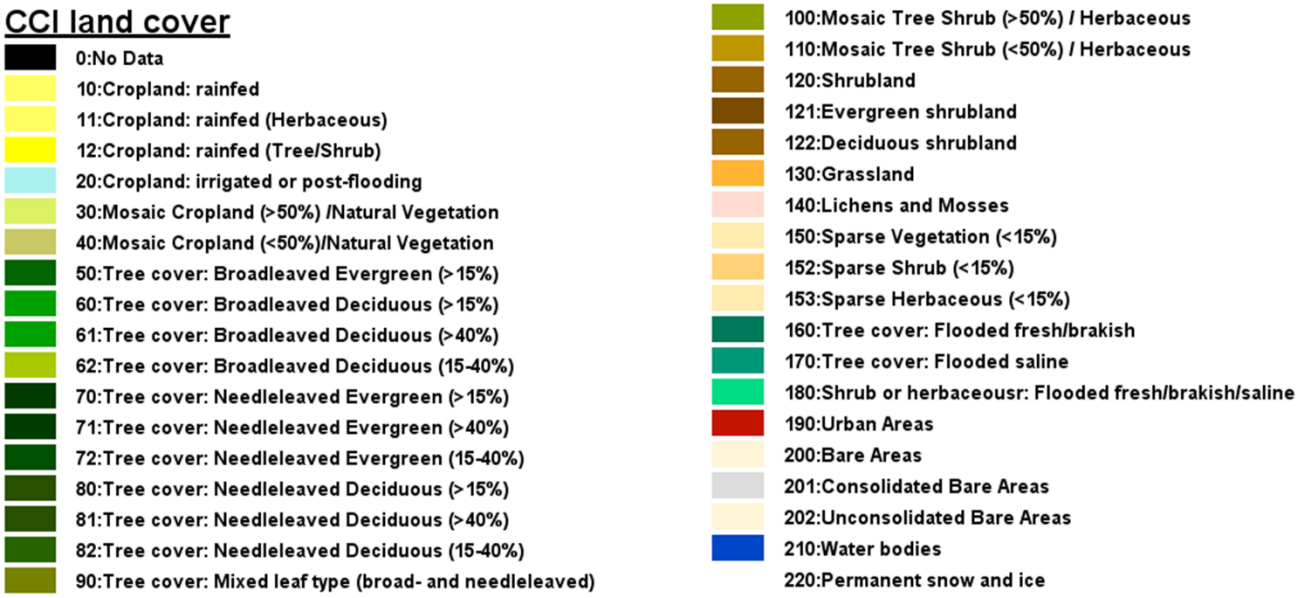


Figure 1: Global land cover map (ESA CCI epoch 2010) (top) and legend (bottom) derived from ENVISAT MERIS and SPOT-VGT data.

2.2.3 Processing steps

The input fAPAR product has small values over non vegetated areas, like deserts. This results in a positive DMP/GDMP/NPP/GPP value that are not realistic. Therefore, the low values of fAPAR are removed in the following way (see also Figure 2):

(1) All FAPAR values ≤0.05 are set to 0

(2) All FAPAR values >0.05 and <0.15 are rescales linearly between 0 and 0.15

(3) All fAPAR values ≥0.15 remain unchanged.

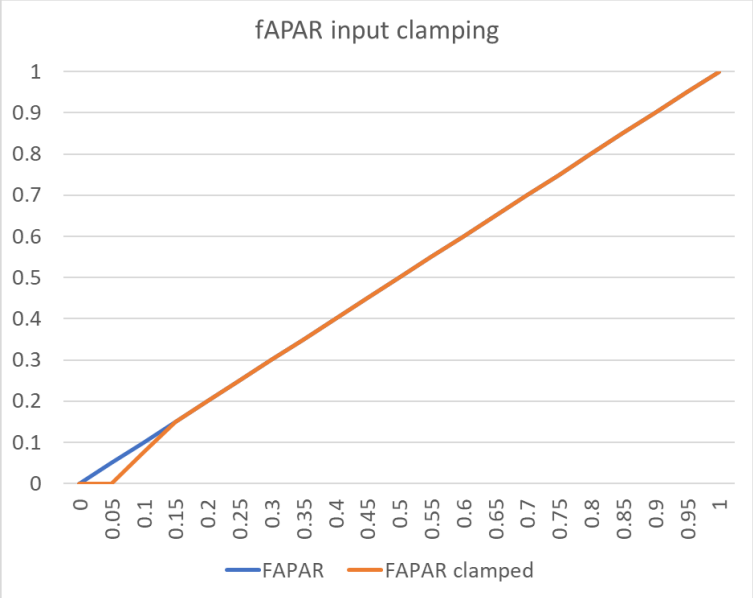


Figure 2: fAPAR clamping method.

The GDMP and DMP product of the Global Land service is currently computed with the following Monteith variant (see Table 2):

$$GDMP = R \times \varepsilon_c \times fAPAR \times \varepsilon_{LUEc} \times \varepsilon_T \times \varepsilon_{CO2}[\times\varepsilon_{RES}] \quad (3)$$

$$DMP = R \times \varepsilon_c \times fAPAR \times \varepsilon_{LUEc} \times \varepsilon_T \times \varepsilon_{CO2} \times CUE[\times\varepsilon_{RES}] \quad (4)$$

Table 2: Individual terms in the Monteith variant used for Global Land service GDMP/DMP. All terms are expressed on a daily basis.

TERM	*MEANING*	*VALUE*	*UNIT*
GDMP	Gross Dry Matter Productivity	0 - 640	kgDM/ha/day
DMP	Dry Matter Productivity	0 – 320	kgDM/ha/day
R	Total shortwave incoming radiation (0.2 – 3.0µm)	0 – 320	GJ_T/ha/day
ε_c	Fraction of PAR (0.4 – 0.7µm) in total shortwave	0.48	J_P/J_T
*f*APAR	PAR-fraction absorbed (AP) by green vegetation	0.0 ... 1.0	J_{AP}/J_P
ε_{LUEc}	Light use efficiency (DM=Dry Matter) at optimum	Biome-specific	$kgDM/GJ_{AP}$
ε_T	Normalized temperature effect	0.0 ... 1.0	-
ε_{CO2}	Normalized CO_2 fertilization effect	0.0 ... 1.0	-
CUE	Carbon Use Efficiency (GPP/NPP or GDMP/DMP ratio)	0.5	-
ε_{RES}	Fraction kept after omitted effects (drought, pests...)	1.0	-

A detailed description of the terms is given in the ATBD [CGLOPS1_ATBD_DMP-NPP300m-V1.1].

Given the simple elaboration of the epsilons (and dropping the factor ε_{RES}), equation (3) and equation (4) can be rewritten as:

$$\mathbf{GDMP = R \times \varepsilon_c \times fAPAR \times \varepsilon_{LUEc} \times \varepsilon_T \times \varepsilon_{CO2} = fAPAR \times \varepsilon_{LUEc} \times R \times \varepsilon(T,CO_2) = fAPAR \times \varepsilon_{LUEc} \times GDMP_{max}} \quad \mathbf{(5)}$$

$$\mathbf{DMP = GDMP \times CUE = GDMP \times 0.5} \quad \mathbf{(6)}$$

with $\varepsilon(T,CO_2) = \varepsilon_c \times \varepsilon_T \times \varepsilon_{CO2}$ and ε_{LUEc} is the land cover specific LUE. This formulation better highlights the fact that (within the limits of the described model) GDMP is only determined by four basic factors: *f*APAR, radiation (R), temperature (T) and CO_2. At the same time, equation (5) provides a practical method which allows bypassing the differences in temporal and spatial resolution between the inputs. In practice, the meteorological inputs (R, T) are provided on a daily basis and at a very low resolution, here 0.25° × 0.25°. On the contrary, *f*APAR is provided on a dekadal basis, having pixels with a size of around 300x300m. The ESA CCI land cover map is also applied at 300m

resolution to include the Light Use Efficiency (LUE or ε_{LUEc}) factor. Then, the final GDMP/DMP-product has this 300m resolution and dekadal frequency.

So, in practice, we use the procedure (Eerens et al., 2004) illustrated in Figure 3 and can be formulated as follows (the subscripts 1 and 10 indicate daily and dekadal products, N_d is the number of days in each dekad)

$$GDMP_{10} = fAPAR_{10} \times \varepsilon_{LUEc} \times GDMP_{max,10} \quad \text{with} \quad GDMP_{max,10} = \{\Sigma GDMP_{max,1}\} / N_d \qquad (8)$$

$$DMP_{10} = GDMP_{10} \times CUE \quad \text{with} \quad CUE = 0.5 \qquad (9)$$

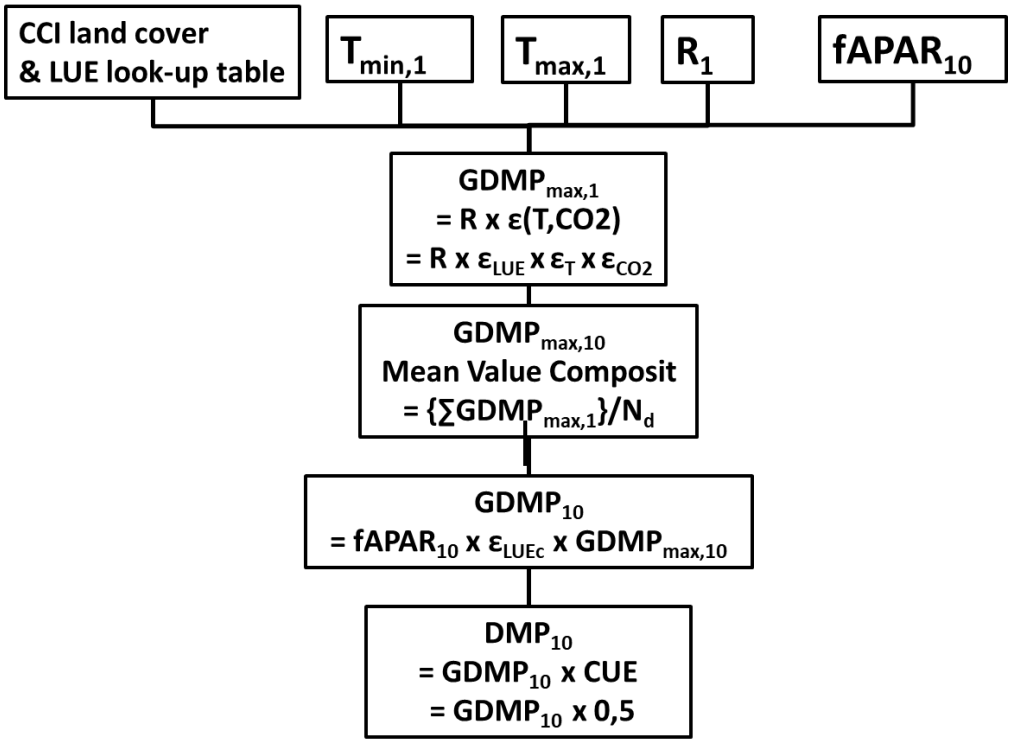


Figure 3: Process flow of GDMP/DMP. Based on meteorological data, a daily GDMPmax is estimated. At the end of each dekad, a Mean Value Composite of these GDMPmax images is calculated. At the same time, a 10-daily fAPAR product is generated. The final $GDMP_{10}$ product is retrieved by the simple multiplication of the latter two images and, then, converted to DMP_{10}.

NPP and GPP are derived from DMP and GDMP using the following formulae:

$$NPP\ [gC/m^2/day] = DMP\ [kgDM/ha/day] \times 0.5 \times 0.1 \qquad (10)$$

$$GPP\ [gC/m^2/day] = GDMP\ [kgDM/ha/day] \times 0.5 \times 0.1 \qquad (11)$$

2.2.4 Near Real Time retrieval of the DMP (NPP) 300m Version 1.1

The details of the algorithm are described in the ATBD [CGLOPS1_ATBD_DMP-NPP300m-V1.1].

The production of the DMP (NPP) is managed similarly to the production of FAPAR Collection 300m Version 1.1. A brief description is given below but the reader is also referred to the product user manual of this fAPAR [CGLOPS1_PUM_FAPAR300m-V1.1]. A distinction is made between the past-time series production and the near real time products.

The compositing for real time estimates is achieved according to the scheme described in Figure 4. We consider a particular dekadal date, *D*.

- In real time mode (RT0) (when the actual date corresponds to *D*, i.e. the first line in Figure 4), the compositing is achieved using only the past observations, with a maximum compositing window spanning c_- days in the past. The value of the product at dekadal date *D* is therefore relatively inaccurate.
- Then, the observations accumulate after dekadal date *D* when time passing. The value at dekadal date *D* is updated using the observations available after dekadal date *D* within the consolidation period. The accuracy of the product value progressively improves during this consolidation period.
- At the end of the consolidation period that lasts c_+ days, the value of the product value at dekadal date *D* have converged towards the 'historical' value, i.e. when there is at least c_- days (maximum length of the compositing window) after dekadal date *D*.

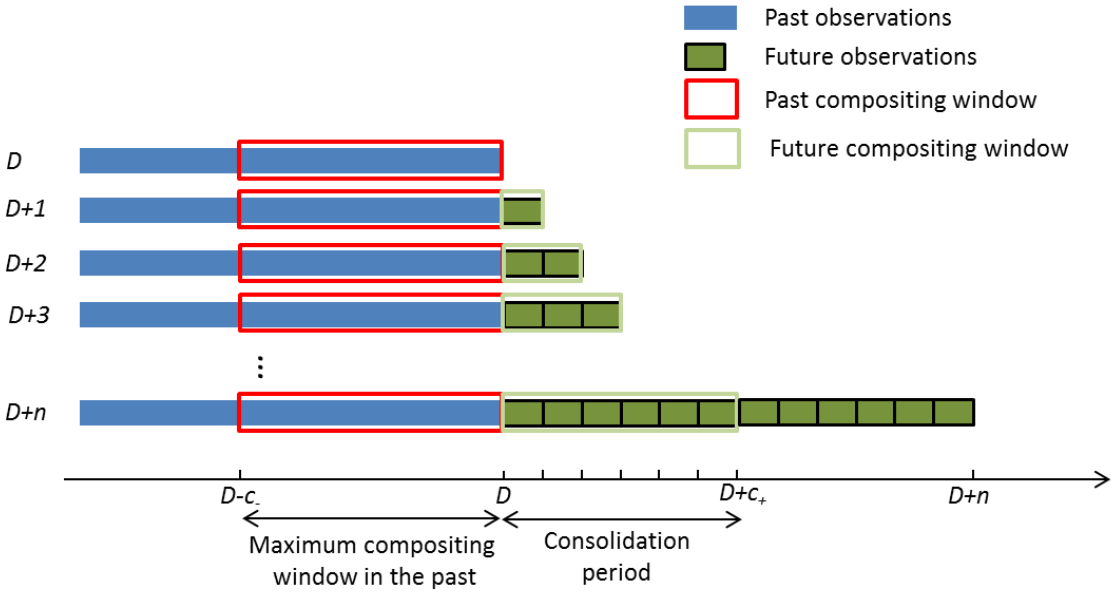


Figure 4: Scheme showing the compositing used for real time estimates

Note that the compositing period is not symmetric: the maximum compositing window in the past is longer than the maximum compositing window in the future (after date *D*) that is limited by the length of the consolidation period. The length of the maximum compositing window is set to 60 days, however more daily observations are used to classify the pixel as Evergreen Broadleaf Forest (EBF) or no-EBF. If not enough daily observations are available to estimate the dekadal value, either an interpolation with the surrounding dekads is performed or in case of EBF the value will be based on the previous dekadal value.

Once a new dekad is available after dekadal date D, the value of the product at dekadal date D is updated and replaces the previous update. This allows saving significant space. The reliability of the estimate will increase with the consolidations. The product is provided in the following consolidations: RT0 (at dekad D), RT1 (at dekad D+1), RT2 (at dekad D+2) and RT6 (at dekad D+6).

2.3 DIFFERENCES WITH THE PREVIOUS VERSION

The only difference between DMP 300m V1.0 and DMP 300m V1.1 is that V1.0 is derived from the FAPAR 300m V1.0 based upon PROBA-V data while V1.1 is derived from the FAPAR 300m V1.1. based upon Sentinel-3 OLCI data. The differences between FAPAR 300m V1.0 and FAPAR 300m V1.1 are described in Section 4.5. of [CGLOPS1_ATBD_FAPAR300m-V1.1].

2.4 LIMITATIONS

Following remarks should be taken into consideration when interpreting the DMP (NPP) products:

- Some potentially important factors, such as drought stress, nutrient deficiencies, pests and plant diseases, are omitted in the DMP (NPP) product. As a consequence, the product might better be called “potential” DMP or NPP. Especially for drought events, which has the strongest impact on GPP, the current DMP is expected to overestimate biomass production. Only when the adverse effects of these residual vegetation stresses (drought, diseases and shortages of nutrients) impact the RS-derived fAPAR, it will be captured by the DMP and NPP.
- The biome-specific LUE’s are calibrated against flux tower Eddy Covariance (EC) data. These flux data are considered as ground truth measurements of GPP. But, in fact, this GPP is a combination of Net Ecosystem Exchange (NEE) measurements and a modelled respiration factor. Additionally, there are other reasons to question the relation between flux measurements and modelled GPP estimates. The spatial representativeness of the tower, for example, is strongly dependent on local conditions like the towers footprint, wind direction, etc. Thus, caution should be made when comparing 1 km pixel values with tower observations. Each tower also has its specific environmental conditions, like soil properties, precipitation, elevation, … This makes it difficult to generalize tower specific parameterization into broad categories like land cover.

- The biome-specific parametrization requires accurate information on the land cover type. At global scale, a land cover map will always contain a fraction of misclassified pixels.
- The in-situ data availability can determine the reliability of the biome-specific LUE's. For example, for needlelaved deciduous forests, data from only one tower is available.
- The DMP algorithm does not include a water stress factor to account for short term drought stresses. In drought-sensitive vegetation types, this formulation can lead to an overestimation of the actual plant productivity. The temperature dependency factor uses generalized values derived from the parameterization on European forests (Veroustraete et al., 2002) and these parameterization may not hold for other biome types and agro-ecological zones. Especially the difference between C3 and C4 vegetation types is pronounced. C3 plants (like the forests used in the current calibration) will have their optimal temperate around 20-25 degrees whereas C4 plants will reach their optimum around 30-35 degrees (Massad et al., 2007; Yamori et al., 2014).
- fAPAR is included in Light Use Efficiency (LUE) models such as the DMP (NPP) to represent in a relative way an observation of the actual uptake of solar radiation by plants. Combined with the modelled response of vegetation LUE to environmental conditions (represented by the meteorological data as model input) satellite based GDMP (GPP) is estimated. The assumed relation between fAPAR and GDMP (GPP) fits fairly well in general but there are a number of known cases where satellite based fAPAR is not capturing sufficiently accurate GPP or GDMP dynamics:
    - Cloud contamination can result in changes in VIs that can confound the real seasonality of the vegetation.
    - Optical sensors lack the capability to detect the full canopy activity of dense vegetation such as tropical forests.
    - Vegetation greenness as reflected by fAPAR is not able to capture seasonal photosynthetic activity of evergreen trees because of the decoupling of greenness and photosynthesis (Huang et al., 2019).
    - A similar decoupling can occur over wintergreen vegetation such as cover crops where fAPAR values are high but there is little or none photosynthetic activity and plant growth. This can result in overestimations of GDMP/DMP or GPP/NPP.
    - In general, the spectral response of vegetation canopy is insufficient to capture drought effects of GDMP or GPP. Furthermore, the spectral sensitivity of vegetation canopies differs between ecosystems. Trees which have deeper roots are most resistant to decreased soil water and will have a lower sensitivity, while the sensitivity is generally higher for cropland, grassland and shrubland (Zhang et al., 2016).
- The autotrophic respiration is calculated as a simple fraction of GDMP or GPP and is therefore assumed to have the same ecophysiological behaviour. In other models (e.g. used for MODIS product retrieval), the autotrophic respiration is considered as an independent component.

- The CO_2 fertilization factor relies on the original definition by Veroustraete (1994). We acknowledge that more sophisticated and state-of-the-art CO_2 fertilization submodels should be developed. But in the Copernicus Global Land Service, the focus is on algorithm implementation rather than on fundamental research on algorithm components. Hence, we have to rely on existing described methods. If state-of-the-art modules are being developed that perform reliably better than the current approach, then it can be considered to implement them in a future version of the GDMP and GPP algorithm.

3 PRODUCT DESCRIPTION

3.1 FILE NAMING

The **Dry Matter Productivity, Gross Dry Matter Productivity, Net Primary Production and Gross Primary Production** Collection 300m Version 1.1 products follow the naming standard:

c_gls_<PROD>[-<RTx>]_<YYYYMMDDhhmm>_<AREA>_<SENSOR>_V<Major.Minor.Run>

where

- <PROD> is either DMP300 (Dry Matter Productivity), GDMP300 (Gross Dry Matter Productivity), NPP300 (Net Primary Production), or GPP300 (Gross Primary production
- <RTx> is an optional parameter. It is uses whenever a real-time product is provided:
  - RT0: Near Real Time product
  - RT1 or RT2: Consolidated Real Time product (in convergence period), where the number equals the number of times the RT0 product was successively updated
  - RT6: Final consolidated Real Time product

  For OFFLINE reprocessing, this parameter is omitted.
- <YYYYMMDDhhmm> gives the temporal location of the file. YYYY, MM, DD, hh, and mm denote the year, the month, the day, the hour, and the minutes, respectively.
- <AREA> gives the spatial coverage of the file. In this case, <AREA> is GLOBE, the name used for the full globe.
- <SENSOR> gives the name of the sensor family used to retrieve the product, so S3 for Sentinel-3.
- <Major.Minor.Run> gives the version number of the product. “Major” increases when the algorithm is updated. “Minor” increases when bugs are fixed or when processing lines are updated (metadata, etc...). “Run” increases whenever a new processing run (with the same major and minor version) is performed without a change in the algorithm (e.g. due to a change in input data). This version refers to Major = 1.

3.2 FILE FORMAT

The DMP/GDMP/NPP/GPP Collection 300m Version 1.1 products are delivered with global coverage in compressed Network Common Data Form version 4 (netCDF4) files with metadata attributes compliant with version 1.6 of the Climate and Forecast (CF) conventions[2].

Separate products are delivered for all variables.

The multi-layer GDMP netCDF files contain the following layers:

- GDMP: Gross Dry Matter Productivity value
- QFLAG : Quality Flag indicator

The multi-layer DMP netCDF files contain the following layers:

- DMP : Dry Matter Productivity value
- QFLAG : Quality Flag indicator

The multi-layer GPP netCDF files contain the following layers:

- GPP: Gross Primary Production value
- QFLAG : Quality Flag indicator

The multi-layer NPP netCDF files contain the following layers:

- NPP : Net Primary Production value
- QFLAG : Quality Flag indicator

Separately from the data file, an xml file containing the metadata conforms to INSPIRE2.1[3] is generated.

For a more user-friendly viewing of the XML metadata, an XSL transformation file can be downloaded on https://land.copernicus.eu/global/sites/cgls.vito.be/files/xml/c_gls_ProductSet.xsl. This file should be placed in the same folder as the XML file.

[2] http://cfconventions.org/
[3] https://inspire.ec.europa.eu/metadata/

The products are delivered as one single global image, covering 180°W to 180°E longitude and 85°N to 65°S latitude. The globe is divided in 36 tiles in longitude and 18 in latitude according to Figure 5. Only the green tiles, covering land, are generated and hence integrated in the global image. The meteorological input is bound from 75°N to 50°S, hence the green tiles outside this window are filled with empty values (Table 4). In winter, the northern hemisphere has fewer valid observations, hence the number of available tiles could be fewer.

Note that continental tiles, as defined as in Table 3 for AFRI and SOAM are distributed over EUMETCast. The distribution is limited to the real-time mode, hence products with file name convention c_gls_DMP300-RT0_* or c_gls_GDMP300-RT0_* or c_gls_GPP300-RT0_* or c_gls_NPP300-RT0_*

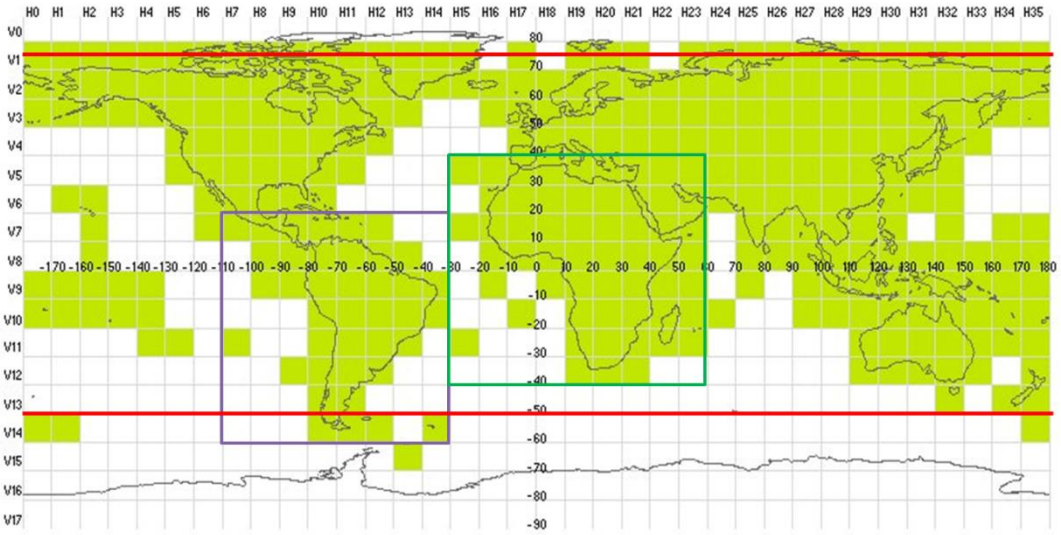


Figure 5: Regions of DMP/GDMP/NPP/GPP product. Red lines indicate the boundaries on availability of meteorological data.

Short name	Continent
AFRI	Africa: 30°W – 60°E, 40°N – 40°S
SOAM	South America: 110°W – 30°W, 20°N – 60°S

Table 3: Definition of the continental tiles distributed via Eumetcast

3.3 PRODUCT CONTENT

3.3.1 Data Files

Table 4 gives the digital numbers associated with the physical DMP, GDMP, NPP and GPP range and no data values. Note that no uncertainties are associated to DMP, GDMP, NPP and GDMP values. The physical values are retrieved by:

$$PhyVal = DN \times scale\_factor + add\_offset$$

where the scale_factor and add_offset are given in the table below. This rescaling formula does not apply to the binary numbers representing special flag values (Table 4).

Table 4: Range of values and scaling factors of GDMP/DMP/GPP/NPP.

	GDMP (kg Dry Matter / ha / day)	**DMP** (kg Dry Matter / ha / day)	**GPP** (g C / m² / day)	**NPP** (g C / m² / day)
Minimum value	0	0	0	0
Maximum value	655.34	327.67	32.767	16.3835
Maximum DN value	32767	32767	32767	32767
Missing value	-1	-1	-1	-1
Specific value for sea	-2	-2	-2	-2
Scale_factor	0.02	0.01	0.001	0.0005
Add_offset	0	0	0	0

Once properly decoded, the physical DMP (GDMP) values range between 0 and 327.67 (655.34) kg dry matter per hectare per day, and the physical NPP (GPP) values range between 0 and 16.3835 (32.767) kg carbon per square meter per day. The lowest values are found over non-vegetated areas like deserts, urban areas or outside the growing season in cold climate zones. The highest values indicate high productive pixels, often found over forested areas in the peak of the growing season or in tropical zones.

3.3.2 QFLAG image

In addition to the quality flags in the negative range of the data image (Table 4), the quality of the GDMP/DMP/GPP/NPP product is also directly linked to the quality of the input fAPAR.

Table 5 provides the DMP/GDMP/NPP/GPP 300m version 1.1 QFLAG layer. This layer is derived from the FAPAR 300m V1.1 quality indicator as referenced in the last column of the table.

Table 5: Range of values of QFLAG.

Bit	Qualitative indicator	Meaning	Mapping on fAPAR300
1	fAPAR missing or invalid	0 = Available fAPAR300 value 1 = Missing fAPAR300 value	fAPAR = 255
2	Meteorological data missing or invalid	0 = Available Meteorological values 1 = Missing Meteorological values	-
3	Not used		
4	Evergreen Broadleaf Forest (EBF)	1 = EBF 0 = no EBF	QFLAG bit 2
5	Not used		
6	Low fAPAR correction	1 = fAPAR<0.15 and rescaled according to Figure 2 0 = fAPAR is unchanged	
7	fAPAR computation for EBF	0 = fAPAR from daily observations 1 = fAPAR filled from previous dekad	QFLAG bit 5
8	fAPAR gap filling by interpolation	0 = fAPAR not interpolated 1 = fAPAR interpolated	QFLAG Bit 3

3.3.3 File and Layer attributes

The netCDF file contains a number of attributes

- at the file-level, see Table 6
- at the level of the variables (layers), see Table 7 and Table 8
- at the level of the standard coordinate (dimension) variables for latitude (‘lat’) and longitude (‘lon’), holding one value per row or column respectively: see Table 9
- at the level of the grid mapping (spatial reference system) variable (named ‘crs’): see Table 10

- at the level of time coordinate, see Table 11

Table 6: Description of NetCDF file attributes

Attribute name	Description	Data Type	Example
Conventions	Version of the CF-Conventions used	String	CF-1.6
title	A description of the contents of the file	String	10-daily Dry Matter Productivity 333M: GLOBE 2023-09-10T00:00:00Z
institution	The name of the institution that produced the product	String	VITO NV
source	The method of production of the original data	String	Derived from EO satellite imagery
history	A global attribute for an audit trail. One line, including date in ISO-8601 format, for each invocation of a program that has modified the dataset.	String	2023-09-12 Processing line DMP300
references	Published or web based references that describe the data or methods used to produce it.	String	https://land.copernicus.eu/global/products/dmp
archive_facility	Specifies the name of the institution that archives the product	String	VITO
product_version	Version of the product (VM.m.r)	String	V1.1.1
time_coverage_start	Start date and time of the total coverage of the data for the product.	String	2023-09-01T00:00:00Z
time_coverage_end	End date and time of the total coverage of the data for the product.	String	2023-09-10T23:59:59Z
platform	Name(s) of the orbiting platform(s)	String	Sentinel-3
sensor	Name(s) of the sensor(s) used	String	OLCI
identifier	Unique identifier for the product	String	urn:cgls:global:dmp300_v1_333m:DMP300_202309100000_GLOBE_S3_V1.1.1

Attribute name	Description	Data Type	Example
parent_identifier	Identifier of the product collection (time series) for the product in Copernicus Global Land Service metadata catalogue.	String	urn:cgls:global:dmp300_v1_333m
long_name	Extended product name	String	Dry matter productivity Net Primary Production
orbit_type	Orbit type of the orbiting platform(s)	String	LEO
processing_level	Product processing level	String	L3
processing_mode	Processing mode used when generating the product (Near-Real Time, Consolidated or Reprocessing)	String	Near Real Time
copyright	Text to be used by users when referring to the data source of this product in publications (copyright notice)	String	Copernicus Service information 2020

Table 7: Description of NetCDF layers attributes for DMP/GDMP

Attribute	Description	Data Type	Examples for DMP layer
CLASS	Dataset type		
long_name	A descriptive name that indicates a variable's content. This name is not standardized. Required when a standard name is not available.	String	Dry matter productivity 333M
scale_factor	Multiplication factor for the variable's contents that must be applied in order to obtain the real values. Omit in case the scale is 1.	Float	0.01
add_offset	Number to be added to the variable's contents (after applying scale_factor) that must be applied in order to obtain the real values. Omit for offset 0.	Float	0.0
units	Units of a the variable's content, taken from Unidata's udunits library. Empty or omitted for dimensionless variables. Fractions should be indicated by scale_factor.	String	kg / hectare / day
valid_range	Smallest and largest values for the variable. Missing data is to be represented by one or several values outside of this range.	Same as data variable	0, 32767
_FillValue	Single value used to represent missing or undefined data and to pre-fill memory space in case a non-written part of data is read back. Value must be outside of valid_range.	Same as data variable	-1
missing_value	Single value used to represent missing or undefined data, for applications following older versions of the standards. Value must be outside of valid_range.	Same as data variable	-1
grid_mapping	Reference to the grid mapping variable	String	Crs
flag_values	Provides a list of the flag values. Used in conjunction with flag_meanings.	Same as data variable	-2
flag_meanings	Descriptive phrases for each flag value, separated by blanks	String (blank separated list)	Sea

Table 8: Description of NetCDF layers attributes for NPP/GPP

Attribute	Description	Data Type	Examples for NPP layer
CLASS	Dataset type		
long_name	A descriptive name that indicates a variable's content. This name is not standardized. Required when a standard name is not available.	String	Net Primary Production 333M
scale_factor	Multiplication factor for the variable's contents that must be applied in order to obtain the real values. Omit in case the scale is 1.	Float	0.0005
add_offset	Number to be added to the variable's contents (after applying scale_factor) that must be applied in order to obtain the real values. Omit for offset 0.	Float	0.0
units	Units of the variable's content, taken from Unidata's udunits library. Empty or omitted for dimensionless variables. Fractions should be indicated by scale_factor.	String	g / m² / day
valid_range	Smallest and largest values for the variable. Missing data is to be represented by one or several values outside of this range.	Same as data variable	0, 32767
_FillValue	Single value used to represent missing or undefined data and to pre-fill memory space in case a non-written part of data is read back. Value must be outside of valid_range.	Same as data variable	-1
missing_value	Single value used to represent missing or undefined data, for applications following older versions of the standards. Value must be outside of valid_range.	Same as data variable	-1
grid_mapping	Reference to the grid mapping variable	String	Crs
flag_values	Provides a list of the flag values. Used in conjunction with flag_meanings.	Same as data variable	-2
flag_meanings	Descriptive phrases for each flag value, separated by blanks	String (blank separated list)	Sea

Table 9: Description of NetCDF coordinate variable attributes

Attribute	Description	Data Type	Example
CLASS	Dataset type	String	DIMENSION_SCALE
DIMENSION_LABELS	Label used in netCDF4 library	String	Lon
NAME	Short name	String	Lon
standard_name	A standardized name that references a description of a variable's content in CF-Convention's standard names table. Note that each standard_name has corresponding unit (from Unidata's udunits).	String	longitude
long_name	A descriptive name that indicates a variable's content. This name is not standardized. Required when a standard name is not available.	String	longitude
units	Units of the variable's content, taken from Unidata's udunits library.	String	degrees_east
axis	Identifies latitude, longitude, vertical, or time axes.	String	X
_CoordinateAxisType	Label used in GDAL library	String	Lon

Table 10: Description of NetCDF grid mapping variable attributes

Attribute	Description	Data Type	Example
GeoTransform	Six coefficients for the affine transformation from pixel/line space to coordinate space, as defined in GDAL's GeoTransform	String	-180.0000000000 0.0089285714 0.0 80.0000000000 0.0 -0.0089285714
_CoordinateAxisTypes	Label used in GDAL library	String, blank separated	GeoX GeoY
_CoordinateTransformType	Type of transformation	String	Projection
grid_mapping_name	Name used to identify the grid mapping	String	latitude_longitude
inverse_flattening	Used to specify the inverse flattening (1/f) of the ellipsoidal figure associated with the geodetic datum and used to approximate the shape of the Earth	Float	298.257223563
long_name	A descriptive name that indicates a variable's content.	String	coordinate reference system
longitude_of_prime_meridian	Specifies the longitude, with respect to Greenwich, of the prime meridian associated with the geodetic datum	Float	0.0
semi_major_axis	Specifies the length, in metres, of the semi-major axis of the ellipsoidal figure associated with the geodetic datum and used to approximate the shape of the Earth	Float	6378137.0
spatial_ref	Spatial reference system in OGC's Well-Known Text (WKT) format	String	GEOGCS["WGS 84",DATUM["WGS_1984",… AUTHORITY["EPSG","4326"]]

Table 11: Description of NetCDF attributes for time coordinate variable

Attribute	Description	Data Type	Example
CLASS	Dataset type	String	DIMENSION_SCALE
NAME	Short name	String	time
long_name	A descriptive name that indicates a variable's content. This name is not standardized. Required when a standard name is not available.	String	Time
units	Units of the variable's content, taken from Unidata's udunits library.	String	Days since 1970-01-01 00:00:00
axis	Identifies latitude, longitude, vertical, or time axes.	String	T
calendar	Specific calendar assigned to the time variable, taken from the Unidata's udunits library.	String	standard

3.4 PRODUCT CHARACTERISTICS

3.4.1 Projection and grid information

The product is displayed in a regular latitude/longitude grid (plate carrée) with the ellipsoïd WGS 1984 (Terrestrial radius=6378km). The resolution of the grid is 1/360°.

The reference is the centre of the pixel. It means that the longitude of the upper left corner of the pixel is (pixel_longitude – angular_resolution/2.). The product is provided at global scale. However, through a custom order, the user is able to select either region according to his/her needs.

3.4.2 Spatial information

As shown in Figure 5, the DMP/GDMP/NPP/GPP product is provided from longitude 180°W to 180°E and latitude 85°N to 65°S.

3.4.3 Temporal information

The temporal information "YYYYMMDDhhmm" in the filename corresponds to the end date of the dekad, similar to the corresponding FAPAR300 input product.

For example, the file c_gls_DMP300-RT0_202307310000_GLOBE_S3_V1.1.1.nc corresponds to the NRT values for the dekad from 21/07/2023 to 31/07/2023.

The temporal information is detailed in the netCDF attributes time_coverage_start and time_coverage_end and in the XML metadata (by the fields "EX_TemporalExtent : beginPosition" and "EX_TemporalExtent : endPosition"), each expressed as "YYYY-MM-DDTHH:MM::SS", giving the beginning and the end of the 10-days time period, respectively. The startPosition of the 10-days time period is always set to the 01st, 11th or 21st day of the month.

3.5 DATA POLICIES

All users of the Global Land service products benefit from the free and open access policy as defined in the European Union's Copernicus regulation (N° 377/2014 of 3 April 2014) and Commission Delegated Regulation (N° 1159/2013), available on the Copernicus programme's web site, http://www.copernicus.eu/library/detail/248). Products from legacy R&D projects are also provided with free and open action.

This includes the following use, in so far that is lawful:

a) reproduction;
b) distribution;
c) communication to the public;
d) adaptation, modification and combination with other data and information;
e) any combination of points (a) to (d).

EU law allows for specific limitations of access and use in the rare cases of security concerns, protection of third-party rights or risk of service disruption.

By using Sentinel Data or Service Information the user acknowledges that these conditions are applicable to him/her and that the user renounces to any claims for damages against the European Union and the providers of the said Data and Information. The scope of this waiver encompasses any dispute, including contracts and torts claims that might be filed in court, in arbitration or in any other form of dispute settlement.

Where the user communicates to the public on or distributes the **original** DMP/GDMP/NPP/GPP products, he/she is obliged to refer to the data source with (at least) the following statement (included as the copyright attribute of the netCDF file):

Copernicus Service information [Year]

with [Year]: year of publication

Where the user has adapted or modified the products, the statement should be:

Contains modified Copernicus Service information [Year]

For complete acknowledgement and credits, the following statement can be used:

"The products were generated by the Global Land Service of Copernicus, the Earth Observation program of the European Commission. The research leading to the current version of the product has received funding from various European Commission Research and Technical Development programs. The product is based on PROBA-V and Sentinel-3 data (© ESA)."

The user accepts to inform the Copernicus Global Land Service about the outcome of the use of the above-mentioned products and to send a copy of any publications that use these products to the following address helpdeskticket@vgt.vito.be.

3.6 ACCESS AND CONTACTS

The DMP/GDMP/NPP/GPP products are available through the Copernicus Global Land Service website at the address: http://land.copernicus.eu/global/products/ndvi with contact information (helpdesk) on http://land.copernicus.eu/global/contactpage. More details on data access are available on http://land.copernicus.eu/global/access.

Accountable contact: European Commission Directorate – General Joint Research Center

Email address: copernicuslandproducts@jrc.ec.europa.eu

Scientific & Technical Contact e-mail address: helpdeskticket@vgt.vito.be.

4 SUMMARY OF QUALITY ASSESSMENT

The quality of the DMP/GDMP 300m V1.1 is analysed in detail in the Quality Assessment Report [CGLOPS1_QAR_DMP-NPP300m-V1.1]. The quality assessment (QA) of the DMP/GDMP 300m V1.1 is based on the series July 2018 – April 2019, thereby focusing on the temporal stability and consistency, and the accuracy assessment against FLUXNET data. Note that currently the DMP 300m V1.1 product is only available to users from July 2020 onwards.

The QA focused on (1) the difference in consolidation modes of the product, (2) the statistical and temporal consistency between DMP/GDMP 300m V1.1 derived from Sentinel-3 and DMP/GDMP 300m V1 derived from PROBA-V, (3) the statistical and spatial consistency of these two datasets with MOD17 GPP dataset (http://www.ntsg.umt.edu/project/mod17) downloaded from Google Earth Engine (http://earthengine.google.com), (4) the statistical and spatial consistency between DMP/GDMP 300m V1.1 and DMP/GDMP 1km V2, (5) temporal consistency, (6) product completeness, and (7) accuracy assessment with FLUXNET data. The results are summarized here:

1. The differences between RT6 (final consolidation mode) and RT0, RT1 and RT2 are small. The temporal pixel profiles demonstrate that RT6 has the smoothest temporal profile. Small changes to this temporal profile are present in RT2 and RT1. The difference between the temporal profiles of RT6 and RT0 are largest, with occasionally large differences. The statistical analysis confirms these observations: the overall bias between the RT-modes is negligible small, and the difference is expressed in the variability of the relationship. When using DMP/GDMP time series, RT6 is used, complemented with RT2, RT1 and RT0 for the most recent dekads. Therefore, the quality assessment is based mainly on RT6.
2. DMP 300m V1.1 shows very good consistency with DMP 300m V1. The overall bias is close to 0, and the scatterplots show a strong linear agreement with limited scatter. Also, the frequency histograms per biome are almost identical between both data sets. Only for barren areas, slightly higher values are observed for DMP 300m V1.1. It is observed that the images of DMP 300m V1.1 are less sharp compared to PROBA-V DMP 300m V1. This difference is probably related to the spatial characteristics of the sensor: the native resolution of PROBA-V is higher than that of Sentinel-3. It is concluded that the DMP 300m V1.1 can be used as the continuation of the PROBA-V DMP 300m V1 data set.
3. There is positive bias between GDMP 300m V1.1 and MOD17, because GDMP represents a potential GDMP in the absence of water stress, which is opposed to MOD17 that includes water limitation in its algorithm. The magnitude of the bias depends on the biome type, with evergreen broadleaf forest, deciduous broadleaf forest and cropland having the largest bias. These biomes also have the largest uncertainty (high root mean square difference) and the lowest precision (high standard deviation). The bias is almost 0 for bare areas and herbaceous

areas and slightly negative for needleleaf forest, but they also have a larger uncertainty and lower precision.

4. A good agreement between DMP 300m V1.1 and DMP 1km V2 is found. There is a small overall bias, of which the distribution is slightly skewed to negative values. Both data sets have very similar frequency histograms for all biomes. Scatter density plot shows a linear relationship with a geometric mean regression line almost identical to the 1-1 line. It should be noted that for small DMP/GDMP values, the relationship is slightly different. It is concluded that the Sentinel-3 DMP/GDMP 300 V1.1 resampled to 1km with a mean filter can be used as continuation of the Collection 1km DMP/GDMP V2.
5. The temporal behavior of the DMP 300m V1.1 (RT6 and RT0), DMP 300m V1, DMP 1km V2 and MOD17 was compared for a large number of pixels. The temporal behaviour of the CGLS DMP/GDMP products are very similar. The difference is larger with MOD17. This dataset has many more gaps in the temporal pixel profiles compared to the CGLS DMP/GDMP data sets. The smoothness of the CGLS DMP data sets is very similar, with the RT0 having the less smooth profile. MOD17 has the highest relative variation of the all the data sets compared.
6. S3 DMP300 V1.1 (RT6) has a better completeness compared to MOD17, in number of gaps, spatial distribution and temporal evolution. The spatial distribution of the gaps show that they are located in specific areas (northern high latitudes and tropics), whereas MOD17 has gaps on all vegetated land surfaces. This pattern is also the case for DMP 300m V1.1 RT0. The temporal evolution shows a clear seasonality with less observations during winter. Sentinel-3 DMP300 V1.1 has a similar completeness as PROBA-V DMP300 V1. However, more gaps are observed, and the difference in percentage valid pixels is largest in the earlier months when only Sentinel-3A was available to use. The completeness needs therefore to be re-assessed once a longer time series is available. PROBA-V DMP 1km V2 shows the best completeness of all data sets analysed. The use of a climatology in the PROBA-V FAPAR 1km V2 retrieval provides more values and fewer (small) gaps.
7. GDMP 300m V1.1 was validated against FLUXNET data over Europe only. The bias between the S3 GDMP300 V1.1 and FLUXNET is small (1.92 kg DM/ha/day). The same magnitude of bias is found between the various CGLS GDMP data sets and the FLUXNET data. The bias between MOD17 and FLUXNET is higher (around 10 kg DM/ha/day). The accuracy is thus higher for CGLS GDMP data sets than for MOD17 in this comparison. The uncertainty is high and the precision is low for all data sets compared with FLUXNET. The results are influenced by the small sample size and the fact that the analysed time series mainly covers the period outside the growing season where GDMP is low. In addition, the footprint of the FLUXNET data does not entirely correspond with the satellite footprint used in the comparison, and the FLUXNET footprint changes over time due to wind direction and speed. Also, GPP derived from eddy covariance measurements are also based on a model, that is

error prone. It is advised to update the accuracy assessment once a longer time series is available.

In conclusion, the CGLS Sentinel-3 DMP 300m V1.1 product shows high product completeness, good stability and large statistical consistency with the reference products. The consistency is the largest with the PROBA-V-based CGLS DMP products at 300m and 1km. The Sentinel-3 DMP 300m V1.1 can be considered as the continuation of these datasets.

It should be pointed out that only in-situ data from Europe were used to assess the accuracy of the product. Yet, there is large consistency with the PROBA-V DMP 300m V1 that was validated on multiple years of data, and globally distributed in-situ data.

The above results are also valid for NPP and GPP, distributed in CGLS since September 2023, as these are a simple rescaling from kg DM/ha/day to gC/m²/day, taking into account the Carbon Use Efficiency (CUE), which is taken as a constant term. For the validation of GDMP with FLUXNET data and with MODIS, these external GPP datasets are rescaled to GDMP using CUE=0.45 (Atjay et al., 1979). For the calculation of the NPP and GPP products, the source of the CUE was updated to CUE=0.5 (IPCC, 2003). A reprocessed time series of DMP, GDMP, NPP and GPP will become available in 2024, and then the Quality Assessment Report will be updated with the latest CUE value.

The QAR formulated the following recommendations:

- The DMP is a constant fraction of 0.5 of the GDMP. In cases where the user has more detailed information on the ratio of DMP/GDMP (or NPP/GPP), we advise the user to make his/her own conversion from GDMP into DMP by simply multiplying the GDMP with the NPP/GPP ratio. Or, in an optimal case, the user has its own autotrophic respiration model or Carbon Use Efficiency (CUE) approach which can be used to convert GDMP into DMP.
- When using the DMP to quantify biomass accumulation, we advise to compare the results with in-situ data, if available. In some case, the accuracy of the product can be improved by applying a regression correction factor (obtained from the comparison with in-situ data) on the original DMP values.
- The current version of the GDMP/DMP does not have an explicit water limitation factor included and thus only includes the longer-term (days-weeks) drought stress as observed by the FAPAR. If the impact of short terms droughts should be included, the user should multiply the GDMP/DMP with a water limitation factor, for example based on the relation between actual and potential evapotranspiration or soil moisture.
- The LUE parameter is now scaled per land cover. Hence, it is possible that patterns are visible reflecting the land cover areas. We recommend the user to analyse the ESA CCI land cover map for its region.
- The Sentinel-3/OLCI DMP 300m V1.1 is continuously provided in Near Real Time. Each dekad, the most recent dekad is distributed (RT0) and the previous six dekads are updated

(RT1-RT6). RT6 is the consolidated and most stable version. For operational use, e.g. early warning, RT2, RT1 and RT0 can be used for the most recent dekads together with the RT6 time series. For historical analysis such as trend detection, the user is advised to work only on the consolidated RT6 products.

- The definition of the User requirements should be reviewed. Optimal requirements should be the most stringent requirement compared to Target and Threshold. More pixels meeting the Optimal than the other requirements suggest that the Target and Threshold requirements are not well defined.

5 PRODUCT USAGE

5.1 TYPICAL USE

The DMP/GDMP/NPP/GPP products are provided in a single image and are commonly visualized through specialized software or via quicklooks. Note that, in order to retrieve actual DMP/GDMP from the products, the digital numbers have to be divided by 100 (Table 4) or 50 for the GDMP. Similarly, the NPP products should be multiplied with 0.00045 and the GPP values with 0.0009 (Table 4). Missing values due to clouds or snow/ice and water are indicated with special flags (see also Table 4).

The values are classified into a number of classes and colour-coded for easy interpretation. Country, province or district boundaries and a lat/lon grid are superposed on the map. An example of such a quicklook for DMP is provided below in Figure 6.

These visual representations of the Dry Matter Productivity or Net Primary Production product can then be inspected to identify zones of high or low productivity and as such they are useful for general evaluations of the ecosystem productivity of an area.

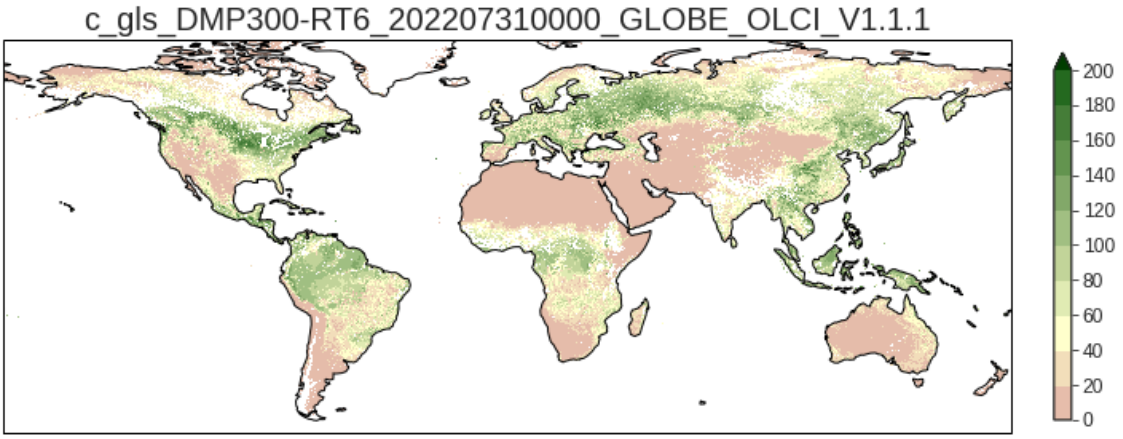


Figure 6 : Global DMP map of the last dekad of July 2022. DMP is expressed in kg DM/ha/day.

5.2 ADVANCED USAGE: HOW TO ANALYZE THE DATA

The examples shown below are from DMP Collection 1km Version 1 product. Similar usage can be done with DMP/NPP Collection 300m product.

For dry matter productivity assessment over the growing season, an analysis needs to be made of a multi-temporal set of those images so that the progress of the growing season and changing growth rates can be assessed (e.g. by looking at the differences of consecutive images in the same season, or by comparing to previous years or seasons or long term averages). Alternatively, the Dry Matter

Productivity images (kg/ha/day) can be accumulated over time from the start of the season in order to estimate the final dry matter (kg/ha) that had been produced by the vegetation over time. When properly calibrated against official yield statistics (post-processed) DMP products may be able to be used for crop yield estimation and forecasting.

Possible post-processing operations:

1. Calculation of differences (in absolute values or percentages):
    - Differencing consecutive images in one season makes it possible to assess the progress (evolution) of dry matter productivity and growth rates during the season.
    - Calculation of the differences between current DMP images and images of previous years or seasons or long-term averages, allows the detection of anomalies in vegetation growth, e.g. Figure 7.

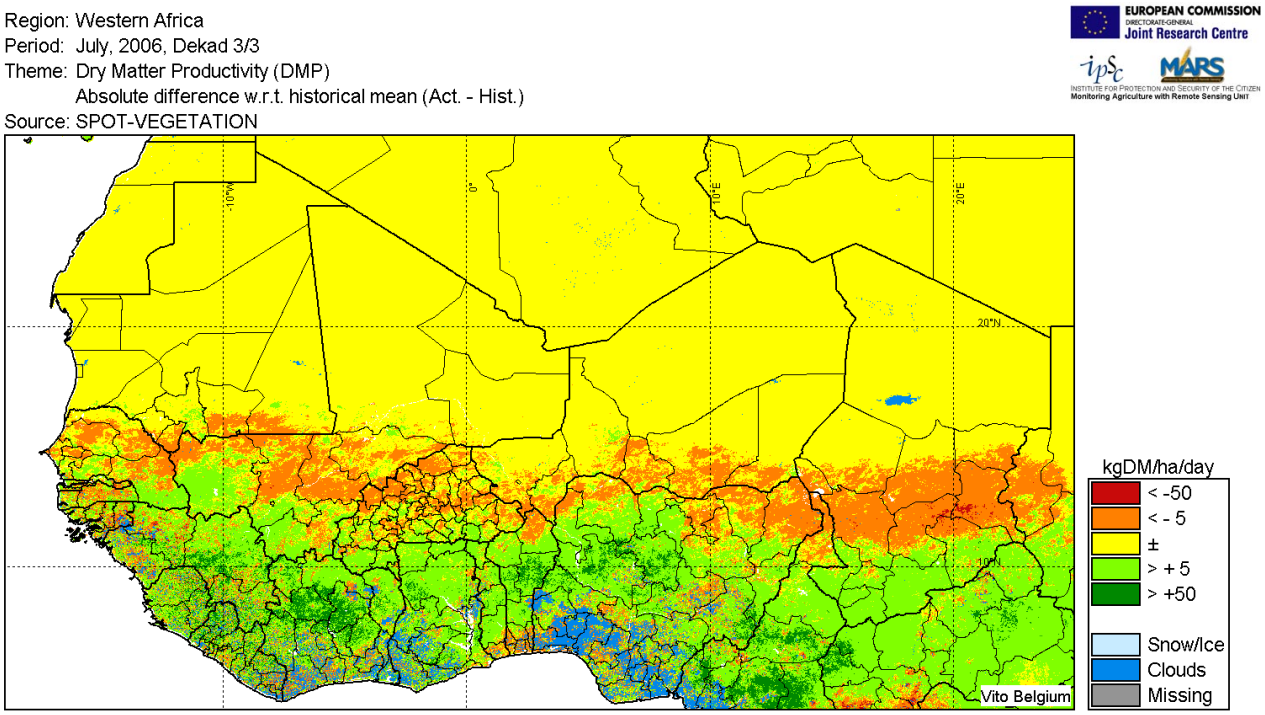


Figure 7 : Western Africa, last dekad of July 2006.
Absolute difference in DMP with respect to long term average. Green = better situation, Red = worse

2. Accumulating DMP over time, from the start of the season onwards, provides estimates of final dry matter production over time, an example in Figure 8.

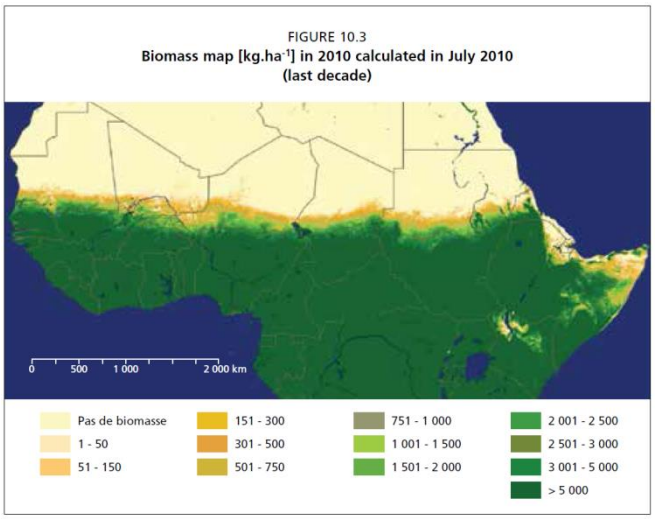


Figure 8 : Sahel, seasonal dry matter productivity as calculated by the Biogenerator software of Action Contre la Faim (NGO). Yellow = low accumulated DMP, Dark green = high accumulated DMP. Map obtained from Ham et al. (2012).

3. Calculation of land cover or crop specific regional means statistics:

   Computation of DMP values per administrative (agro-statistical) unit or other regions (preserved areas, forests) and per land-cover class / crop type further enhances the product for the purpose of dry matter productivity monitoring in specific areas and/or for specific vegetation classes or crop types.

   Several techniques can be used for un-mixing, ranging from the calculation of simple regional means (if no land use information is available), regional means per class or crop type (if per pixel the class/crop type is known), weighted regional means (if per pixel the area fractions of the classes/crops are known) or using more complex techniques as matrix inversion (linear un-mixing) or nonlinear estimation with neural networks. The method to be used mainly depends on the quality of the available information on crop type and location.

   After un-mixing the results are stored in a database. In this way, the image data become compatible with the other agro-statistical information (official areas/yields, model-outputs,…) in a spatial and thematic sense. The agro-statistical region (or district) replaces the pixel as spatial unit, and the class/crop becomes the thematic unit. The procedure also involves an important data reduction.

   By generating graphs from the database the seasonal evolution of the dry matter productivity for a certain region and class/crop can easily be monitored and, in the same way, comparisons can be made with previous years or with the long term average.

In the graph below (Figure 9), DMP profiles are shown for winter cereals in Belgium. Un-mixing was done according to 6 different methods (Verbeiren et al., 2008).

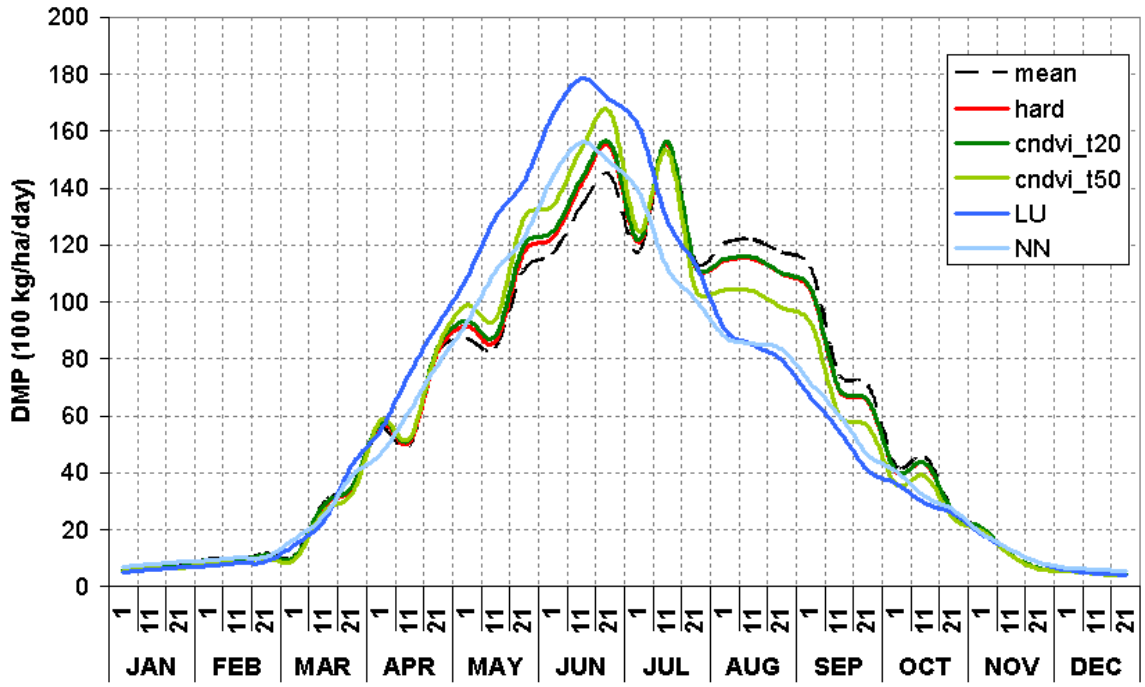


Figure 9 : profiles for DMP for winter cereals in Belgium derived with 6 different un-mixing methods: Regional mean, Hard classification, CNDVI threshold = 20%, CNDVI threshold = 50%, Linear Un-mixing (LU) and Neural Network (NN)

The next figure (Figure 10) describes an example how regional land cover specific statistics can be derived for the Horn of Africa. In this case, the regions are defined by FAO's Global Administrative Unit Layer (GAUL). The land cover information is derived from Africover and GLC2000 classifications. These original maps are resampled to Area Fraction Images (AFI), where each pixel contains the proportion (0-100%) of the area (300x300m=9ha) covered by the concerned class (example: class 10, pastoral dry). In the example a threshold of 50% is specified to withdraw pixels from the computation if their area fraction for a given class is below this threshold. The resulting graph shows the DMP evolution of pastoral dry areas in the Bakool region in Somalia in 2005, 2006 and 2007.

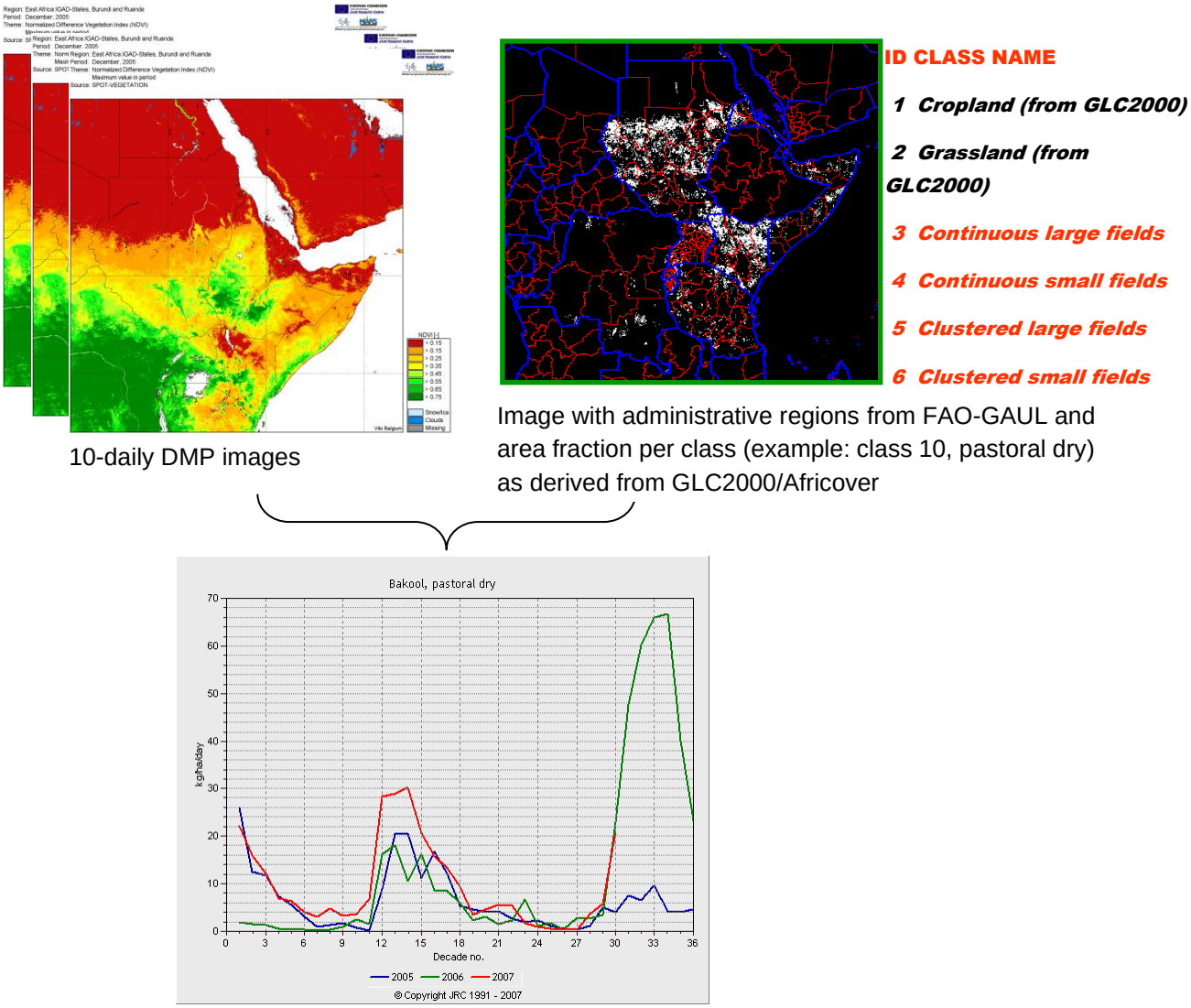


Figure 10 : Regional unmixed means of DMP. Example for the Horn of Africa. Regional unmixed means calculate the average response of DMP for a specific crop within a region weighted by the fraction of occurrence of that crop per pixel.

5.3 USE IN EMPIRICAL REGRESSION MODELLING

The DMP product and in particular the regional and class/crop type specific regional averaged statistics (see above) of the accumulated DMP or maximum DMP (maximum growth rate) are often used for crop yield estimation and prediction, as they are considered to be indicative for agricultural production. Multiple regression and neural networks are the most commonly used techniques to relate

DMP and official yields. Availability of a sufficiently large time series of satellite data and reliable yield statistics is crucial for obtaining good results.

Figure 11 shows an example of the temporal dynamics of yield statistics versus the CGLS DMP at 1 km derived from SPOT-VEGETATION for the period 1999-2012 (Durgun et al., 2016). A comparison is made with a locally adjusted version of the DMP (including a water balance model) and the classical vegetation indices (fAPAR and NDVI). Including the water balance model enhanced the relation between DMP and yield in certain cases but the results were not stable over all sites. Hence this water balance model approach was not adopted in the operational Copernicus DMP.

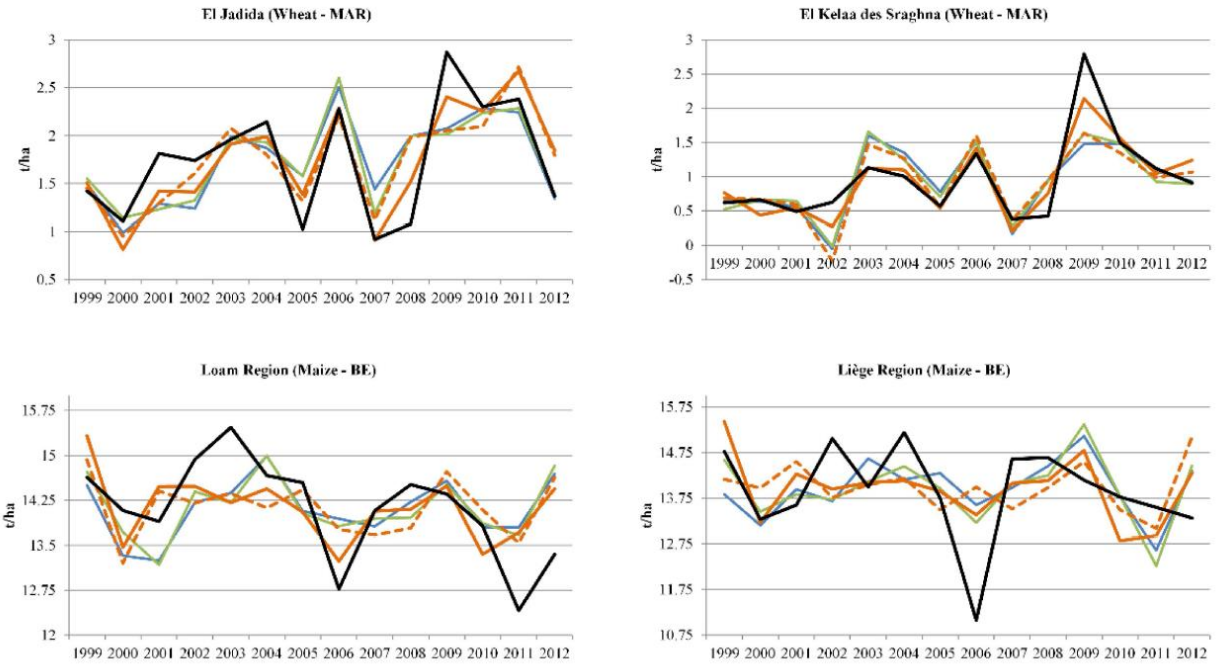


Figure 11: Temporal trends of predicted yield calibrated by leave-one-out cross validation technique confronted with the actual yield for 1999–2012 period per region for Morocco and Belgium. Examples obtained from Durgun et al. (2016). Line color legend: Black=Yield, Solid orange=Modified DMP, Dashed orange=CGLS DMP, Green=fAPAR, Blue=NDVI.

6 REFERENCES

Atjay, G., Ketner, P., Duvigneaud, P., 1979. Terrestrial primary production and phytomass, in: Bolin, B., Degens, E., Kempe, S., Ketner, P. (Eds.), The Global Carbon Cycle, SCOPE 13. John Wiley & Sons, pp. 129–181.

Durgun, Y., Gobin, A., Gilliams, S., Duveiller, G., Tychon, B., 2016. Testing the Contribution of Stress Factors to Improve Wheat and Maize Yield Estimations Derived from Remotely-Sensed Dry Matter Productivity. Remote Sens. 8, 170. https://doi.org/10.3390/rs8030170

Eerens, H., Piccard, I., Royer, A., Orlandi, S., Genovese, G., 2004. Methodology of the MARS Crop Yield Forecasting System. Volume 3: Remote Sensing, data processing and analysis. Joint Research Centre European Commission: Ispra, Italy.

Ham, F., Fillol, E., 2012. Pastoral surveillance system and feed inventory in the Sahel, in: Coughenour, M.B., Makkar, H. (Eds.), Conducting National Feed Assessments. FAO, Rome, Italy (https://www.fao.org/3/i3043e/I3043E.pdf).

IPCC (2003), Good Practice Guidance for Land Use, Land-Use Change and Forestry. Edited by J. Penman et al., 590 p.

Massad, R.-S., Tuzet, A., Bethenod, O., 2007. The effect of temperature on C 4 -type leaf photosynthesis parameters. Plant. Cell Environ. 30, 1191–1204. https://doi.org/10.1111/j.1365-3040.2007.01691.x

Monteith, J.L., 1972. Solar Radiation and Productivity in Tropical Ecosystems. J. Appl. Ecol. 9, 747. https://doi.org/10.2307/2401901

Verbeiren, S., Eerens, H., Piccard, I., Bauwens, I., Van Orshoven, J., 2008. Sub-pixel classification of SPOT-VEGETATION time series for the assessment of regional crop areas in Belgium. Int. J. Appl. Earth Obs. Geoinf. 10, 486–497. https://doi.org/10.1016/j.jag.2006.12.003

Veroustraete, F., 1994. On the use of a simple deciduous forest model for the interpretation of climate change effects at the level of carbon dynamics. Ecol. Modell. 75–76, 221–237. https://doi.org/10.1016/0304-3800(94)90021-3

Veroustraete, F., Sabbe, H., Eerens, H., 2002. Estimation of carbon mass fluxes over Europe using the C-Fix model and Euroflux data. Remote Sens. Environ. 83, 376–399. https://doi.org/10.1016/S0034-4257(02)00043-3

Yamori, W., Hikosaka, K., Way, D.A., 2014. Temperature response of photosynthesis in C3, C4, and CAM plants: temperature acclimation and temperature adaptation. Photosynth. Res. 119, 101–117. https://doi.org/10.1007/s11120-013-9874-6

ANNEX: USER REQUIREMENTS

According to the applicable document [AD1], the requirements relevant for DMP are:

GENERAL PRODUCT SPECIFICATION	
General product specifications, unless otherwise specified in the individual product tables	
Geometric Properties:	
Baseline dataset pixel resolutions	300m,
Target baseline location accuracy	1/3 of the at-nadir instantaneous field of view
Coordinate position	Centre of the pixel
Geodetical datum	WGS84
Geographic projection	regular latitude/longitude grid
Geographic Coverage:	Global
Time span of output product:	At least 10-day period (dekad: days 1-10, 11-20, 21 end of month)

DMP – DRY MATTER PRODUCTIVITY	
Amount (weight) of dry matter (DM) produced per surface unit and per time unit expressed in kilograms of dry matter per hectare per day (kg DM/ha/day). The accumulation over time leads to the assessment of the biomass (in this context, phytomass), and can be defined as above-ground mass per unit are of living plant material (GCOS 107 & 154)	
Reference to current CGLOPS product	https://land.copernicus.eu/global/products/dmp
Uncertainty	Threshold: 20%; target: 10% (can be biome specific: <10% in crop areas; 20% for grassland); Optimal: 5 (in kg DM/ha/day)
Stability	10%
Timeliness of output delivery	Within 72 hrs

NPP –ABOVE GROUND NET PRIMARY PRODUCTION	
Net primary production is the rate at which plants produce net useful chemical energy expressed in mass of carbon per unit area per day(gC/m²/day).	
Reference to current CGLOPS product	https://land.copernicus.eu/global/products/dmp
Uncertainty	Threshold: 20%; target: 10% (can be biome specific: <10% in crop areas; 20% for grassland); Optimal: 5
Stability	10%

Further requirements:

1. Output product composition

Products may contain various information layers and ancillary information – the base reference for product packages are current ATBDs and PUMs (see links provided in the table). Ancillary data shall include at least the following:

- The number of measurements per pixel used to generate the product
- The per-pixel date of the individual measurements or the start dates of the period actually covered
- Quality indicators, with explicit per-pixel identification of the cause of anomalous variable result

2. Data Structure

Data coding[4] shall follow the INSPIRE specifications. Data structure/coding shall initially follow the current ATBDs and PUMs (see links provided in the table above).

3. Data format

To ensure interoperability with the current Global Land component (operational product data formats and archive data formats) and other Copernicus services, all datasets will be available in NETCDF format and/or Cloud Optimized Geotiff (COG) format.

4. Uncertainties and Validation

Uncertainties indicated in the product specifications above relate to: the ideal goal (optimal), as optimum in terms of cost-benefit and technical possibilities (target), and the minimum acceptable (threshold). Wherever different and/or applicable the bio-geophysical variables should meet the internationally agreed accuracy standards laid down in document GCOS-154 (2011) and GCOS-200 (2016).

Levels of uncertainty: the error estimates will account for the uncertainty of the algorithms themselves.

Stability may relate to the existence of a trend between the product and reference ground measured or modelled data.

[4] data coding is the provision for the number of bits, range of values, usage of reserved values, content of status map, conversion to physical values formulas.

Validation of the products shall conform to at least the CEOS LPV standards. Wherever appropriate the bio-geophysical variables shall be validated and compared to CEOS CAL/VAL data sets. The Copernicus in-situ service (https://insitu.copernicus.eu), as well as the Global Land Ground Observation Framework Contract (GBOV) both also provides in situ observations (inclusive 'product' level resampling) that are readily available through the Copernicus web access.

To ensure continuity with the current operation, the same biomes as already used in the Global land component shall be used.

5. Quality Assessment

The Quality assessments will follow the various levels of quality evaluation as currently adapted under the CGLOPS-1 that allow reaching validation stage 4 as defined by the CEOS-LPV (https://lpvs.gsfc.nasa.gov/).